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PHASE 1 ENGINEERING AND TECHNICAL DATA REPORT

For The

THERMAL CONTROL EXTRAVEHICULAR LIFE SUPPORT SYSTEM

March 1975

(NASA-CR-141793) PHASE 1 ENGINEERING AND TECHNICAL DATA REPORT FOR THE THERMAL CONTROL EXTRAVEHICULAR LIFE SUPPORT SYSTEM (Hamilton Standard) 329 p HC $9.50 CSCL 06K N75-24360 Unclas G3/54 21775

Hamilton Standard DIVISION OF UNITED AIRCRAFT CORP

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ABSTRACT

This report presents the results of a comprehensive study to define a Shuttle EVLSS Thermal Control System (TCS). Thirteen Heat Rejection Subsystems, thirteen Water Management Subsystems, nine Humidity Control Subsystems, three pressure control schemes and five temperature control schemes are evaluated. Sixteen integrated TCS systems are studied, and an optimum system selected based on quantitative weighting of weight, volume, cost, complexity and other factors. The selected subsystem contains a sublimator for heat rejection, bubble expansion tank for water management, and a slurper and rotary separator for humidity control. Design of the selected subsystem prototype hardware is presented.

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DEFINITIONS

HRS	Heat Rejection Subsystem
WMS	Water Management Subsystem
HCS	Humidity Control Subsystem
LCG	Liquid Cooling Garment
EVLSS	Extravehicular Life Support System
TCS	Thermal Control System
EVA	Extravehicular Activity
PLSS	Apollo Portable Life Support System
ALSA	Skylab Astronaut Life Support Assembly

1.0 SUMMARY

Hamilton Standard was awarded contract NAS 9-13574 to develop the Shuttle Extravehicular Life Support System (EVLSS) Thermal Control System (TCS) for the Crew Systems Division of the Johnson Space Center. The objective of this program is to select, design, build, and test a zero gravity TCS that meets the Shuttle objectives of long life, low cost, and minimum maintenance.

The TCS consists of a Heat Rejection Subsystem (HRS), a Water Management Subsystem (WMS), and a Humidity Control Subsystem (HCS).

The EVLSS TCS program consists of two phases: 1) concept definition, evaluation, selection, and design of the selected system, and 2) concept fabrication and test.

This report describes the results of the Phase I effort. The basic requirements and operating conditions for the TCS are as follows:

- It must be capable of zero "g" recharge with vehicle supplied water saturated with nitrogen at 248 KPa (36 psia).
- It must be capable of non-venting umbilical operation for up to 4.5 hours.
- It must be operable and capable of rejecting the maximum thermal load within ten minutes of start up (design goal is five minutes).
- There must be no free water spillage when starting up.
- The TCS must be non-venting within five minutes of shutting off feed water.
- The TCS shall have a useful life of 100 mission cycles or 15 years.
- The TCS shall separate and use or store up to .77 Kg (1.7 lbs) of condensate water.
- The total heat load shall be 8.261×10^3 kilo joules (7,824 Btu) (four hours at 293 watts (1,000 Btu/hr) ave. met. load).
- The suit vent loop pressure will be 26.5 ± 1 KPa ($3.85 \pm .15$ psi).
- The liquid loop pressure will be 24 to 158 KPa (3.5 to 22.85 psia).
- The vehicle water supply pressure will be 228 to 248 KPa (33 to 36 psia).

1.0 (Continued)

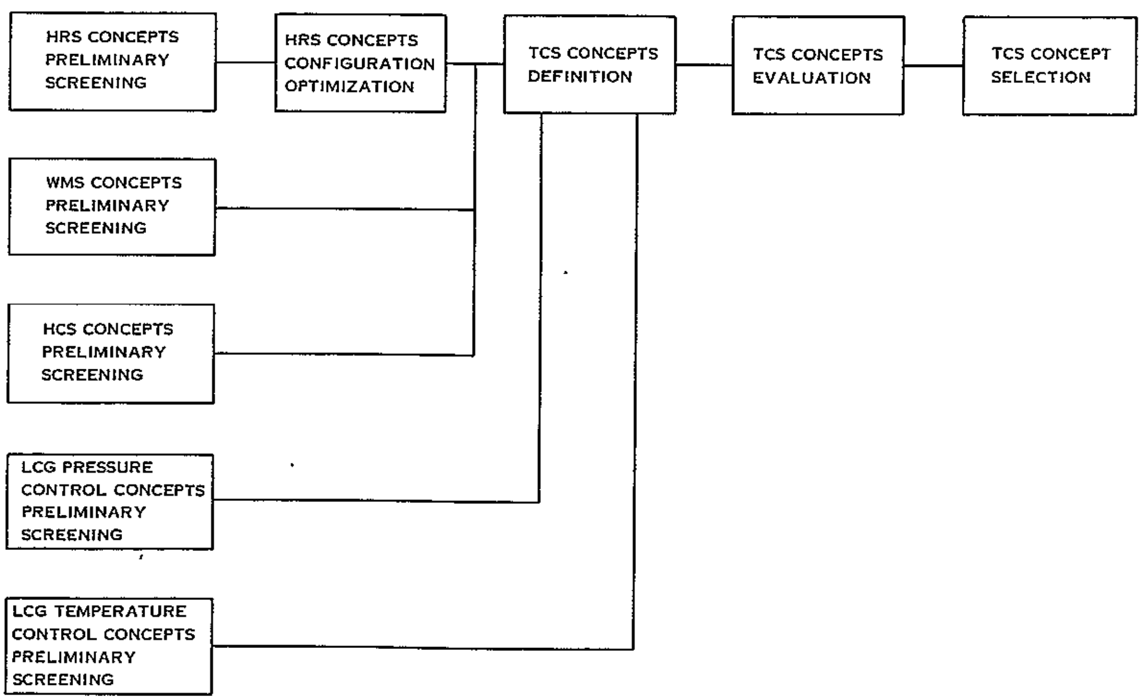
The study consisted of definition of numerous candidate subsystem concepts, selection of competitive subsystem concepts based on an in depth screening evaluation, combination of the competitive subsystems into system concepts and selection of a system concept. Detail drawings of the selected concept were then prepared for fabrication of a feasibility TCS.

The TCS was divided into five sub-areas for investigation.

- Heat Rejection Subsystem (HRS)
- Water Management Subsystem (WMS)
- Humidity Control Subsystem (HCS)
- LCG Pressure Control (Incorporated in WMS)
- LCG Temperature Control (Included in Study Only)

The approach used for each segment of the study consisted of the following steps:

1) Identification of the Evaluation Criteria
2) Identification of the Candidate Concepts
3) Screening of the Concepts
4) Selection of the Optimum Concept(s)



TCS CONCEPT SELECTION STUDY LOGIC

1.0 (Continued)

The HRS was evaluated in two steps. First, identify the viable concepts, and secondly optimize the configuration of these concepts. In the first step of the HRS selection, thirteen candidates were defined and were screened on the basis of safety, performance, development/availability and maintenance. Three promising candidates remained after this evaluation. In the second step of the HRS evaluation, ten configurations for these three concepts were defined and were assessed for life, hardware cost, EVLSS weight and EVLSS volume. This evaluation resulted in the selection of two HRS candidates.

The WMS evaluation consisted of definition of thirteen candidates which were screened on the basis of safety, performance, development/availability, gross vehicle launch weight and EVLSS volume. This evaluation resulted in selection of three WMS candidates for further study.

For the HCS selection, nine candidates were defined and were screened on the basis of safety, performance, development/availability, gross vehicle launch weight and EVLSS volume. Seven candidates were selected for further study.

For the LCG pressure control, three concepts were defined, and two selected after evaluation against safety, performance, development/availability, EVLSS volume and EVLSS weight. In the definition of TCS concepts, the method of pressure control was selected on the basis of compatibility with the systems defined by the HRS, WMS and HCS.

Evaluation of the LCG temperature control consisted of evaluating five candidates against safety, performance, development/availability and EVLSS volume. A single concept was selected for use in the TCS.

The two competitive Heat Rejection Subsystems, three competitive Water Management Subsystems and seven competitive Humidity Control Subsystems were combined to form sixteen candidate Thermal Control Systems. These systems were evaluated on the basis of performance, vehicle launch weight, EVLSS volume, program cost, operability, complexity and reliability. The selected concept, shown in Figure 1-2, was the least weight, least volume, least cost, least complex, most operable and most reliable of the sixteen concepts evaluated.

The selected system consists of a bubble expansion tank water management subsystem, a three-fluid sublimator heat rejection subsystem, and a first stage slurper/second stage motor rotary separator humidity control subsystem. The pump, Temperature Control Valve (TCV), fan and LiOH canister are included in Figure 1-2 to show schematically how the TCS would be integrated into a total EVLSS. During normal operation (venting mode), water enters from the LCG and is circulated by the pump through the vehicle umbilical connector shutoff valve, the sublimator and the temperature control valve and back to the LCG. The LCG water is cooled via conduction to the porous plate of the sublimator. The vent loop flow coming from the suit passes through the LiOH canister and is circulated by the fan through the vent loop portion of the sublimator/slurper and is returned to the suit. Cooling is provided by conduction to the LCG circuit.

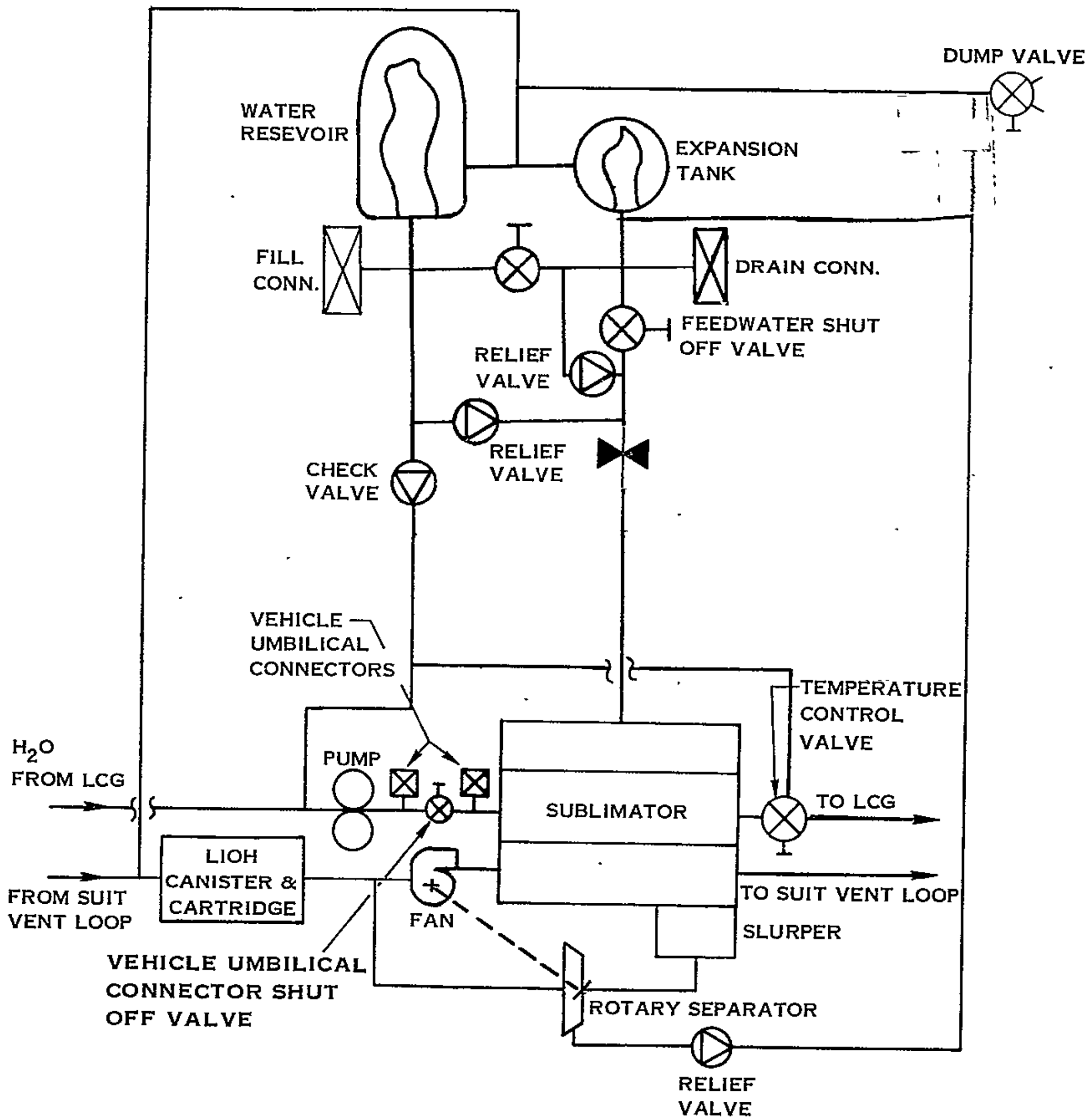


FIGURE 1-2. THERMAL CONTROL SYSTEM

1.0 (Continued)

During operation in the non-venting mode (liquid cooling provided by umbilical to a vehicle heat exchanger) a vehicle liquid umbilical is connected to the system, and the umbilical connector shutoff valve is closed routing all the LCG water through the vehicle heat exchanger.

Coolant thermal control is achieved using the temperature control valve which varies the water flow to the LCG. LCG pressurization and makeup is supplied by the feed water circuit via a check valve between the two circuits.

Water separation is accomplished in two stages. Approximately three percent of the main stream flow is diverted through the slurper to the upstream side of the fan. The pressure differential between these two points continually drains the condensed water from the heat exchanger. The water/gas mixture enters the rotary separator which separates the water from the gas stream. The separated water is delivered to the feed water circuit through a relief valve which prevents the introduction of gas to the feed water circuit.

The expansion tank serves two functions. During operation in the non-venting mode when no feed water is being used, it stores the condensate separated from the vent loop and for operation in the venting mode; it accepts the gas released when the pressure in the main reservior drops from 248 KPa (36 psia) to 27 KPa (4 psia).

This system complies with all requirements, uses extension of proven Apollo technology and was found to be best in all areas after an extensive study of existing and evolving technology and is, therefore, the best suited for the Shuttle EVLSS application.

2.0 INTRODUCTION

In June of 1973, Hamilton Standard was awarded a contract to develop an Extravehicular Life Support System (EVLSS) Thermal Control System (TCS) which is operable in a zero "g" environment for extravehicular activity (EVA) and meets the Space Shuttle criteria of low cost, minimum maintenance, minimum in-flight servicing, minimum ground servicing and long life. This contract is to be completed in two phases with Phase I consisting of the study, selection and design of a TCS consisting of Heat Rejection Subsystem (HRS), Water Management Subsystem (WMS) and Humidity Control Subsystem (HCS) and Phase II consisting of fabrication and testing of each subsystem and the total TCS.

This report summarizes the Phase I effort and describes in detail the definition, screening and selection of each subsystem, the definition evaluation and selection of the TCS and the design of the prototype TCS.

3.0 OBJECTIVES

The objectives of the first phase of this two phase program were:

a. Establish by detail evaluation the best EVLSS Thermal Control System (TCS) which is operable in zero "g" and which meets the Shuttle objectives of long life, minimum maintenance, and low cost.

b. Prepare detail drawings suitable for fabrication of a feasibility TCS.

4.0 DISCUSSION

4.1 Background and Requirements

Hamilton Standard was awarded contract NAS 9-13574 to develop a Shuttle Extravehicular Life Support System (EVLSS) Thermal Control System (TCS) for the Crew Systems Division of Johnson Space Center. The objective of this program is to define and develop a TCS which is operable in a zero gravity environment and meets the Shuttle objectives of long life, low cost and low maintenance.

The TCS program consists of two phases: 1) concept definition, evaluation, selection and design, and 2) concept fabrication and test. This report summarizes the Phase 1 effort. This section of the report includes definition of the TCS requirements; study logic; a summary of the subsystems and system concepts definition, evaluation and selection; and a summary of the TCS design details.

The Thermal Control System consists of a Heat Rejection Subsystem (HRS), a Water Management Subsystem (WMS) and a Humidity Control Subsystem (HCS). The HRS is used to reject heat generated by a crewman and equipment during EVA; the WMS is used to store and deliver expendable water to the HRS; and the HCS is used to separate, store and/or process the condensate generated during an EVA.

The detail requirements for the TCS are defined in a mini specification which is included in Appendix A. Table 4-1-1 is a synopsis of the TCS requirements and operating conditions.

4.2 Study Logic

The Thermal Control System was divided into five sub-areas for investigation.

- Heat Rejection Subsystem (HRS)
- Water Management Subsystem (WMS)
- Humidity Control Subsystem (HCS)
- LCG Pressure Control
- LCG Temperature Control

The approach used in the investigation of each sub-area consisted of:

- Definition of Evaluation Criteria
- Definition of Candidate Concepts
- Evaluation of the Concepts
- Selection of the Optimum Concept(s)

Once the evaluation of the sub-area level was completed, the sub-area concepts that had not been eliminated were combined to form candidate TCS concepts. Final evaluation of concepts was conducted at the system (TCS) level. The HRS, WMS and HCS were the driving factors in defining the TCS concepts, with

TABLE 4-1-1
TCS REQUIREMENTS AND OPERATING CONDITIONS

- It must be capable of zero "g" recharge with vehicle supplied water saturated with nitrogen at 248 KPa (36 psia).
- It must be capable of non-venting umbilical operation for up to 4.5 hours.
- It must be operable and capable of rejecting the maximum thermal load within ten minutes of start up (design goal is five minutes).
- There must be no free water spillage when starting up.
- The TCS must be non-venting within five minutes of shutting off feed water.
- The TCS shall have a useful life of 100 mission cycles or 15 years.
- The TCS shall separate and use or store up to .77 Kg (1.7 lbs) of condensate water.
- The total heat load shall be 8,261 x 10^3 kilo joules (7,824 Btu) (four hours at 293 watts (1,000 Btu/hr) ave. met. load).
- The suit vent loop pressure will be 26.5 $\pm$ 1 KPa (3.85 $\pm$ .15 psi).
- The liquid loop pressure will be 24 to 158 KPa (3.5 to 22.85 psia).
- The vehicle water supply pressure will be 228 to 248 KPa (33 to 36 psia).

4.2 (Continued)

compatible LCG pressure and temperature control concepts being selected for each system concept.

This study logic proceeded as shown in Figure 4-2-1, which shows how the steps used in selecting the final TCS concept were integrated.

4.3 Heat Rejection Subsystem

The Heat Rejection Subsystem (HRS) was evaluated in two steps. First, the basic concepts were screened to identify the viable concepts. Secondly, the viable concepts were configured to identify the optimum configuration for each.

4.3.1 HRS Preliminary Screening Criteria Definition

The determination of the evaluation criteria was based on the recognition that some requirements are absolute while others are relative. The absolute criteria were based on the minimum level of acceptability; thus, concepts which were not compliant with these absolute criteria were rejected without further consideration. Those concepts found to be compliant with the absolute criteria were then rated on a relative basis against selected secondary criteria. In the preliminary screening, two absolute and two relative criteria were used:

Absolute Criteria

Safety - Each concept was evaluated to determine if there were any hazards which could not be eliminated. Specifically, the concept could not present a toxicty hazard, it had to comply with the Apollo fire and explosion requirements, and a component failure could not result in gross vent loop leakage.

Performance - Each HRS concept had to be capable of meeting the following performance requirements:

- It must reach steady state operation within ten minutes of start up.
- It must start up with no spillage.
- It must reach the non-vent mode within five minutes of feed water shutoff.
- It must be possible to prove zero "g" operation in a one "g" gravity field.
- It must operate under low heat load conditions without freeze up.
- It must operate under high heat load conditions without carry-over.

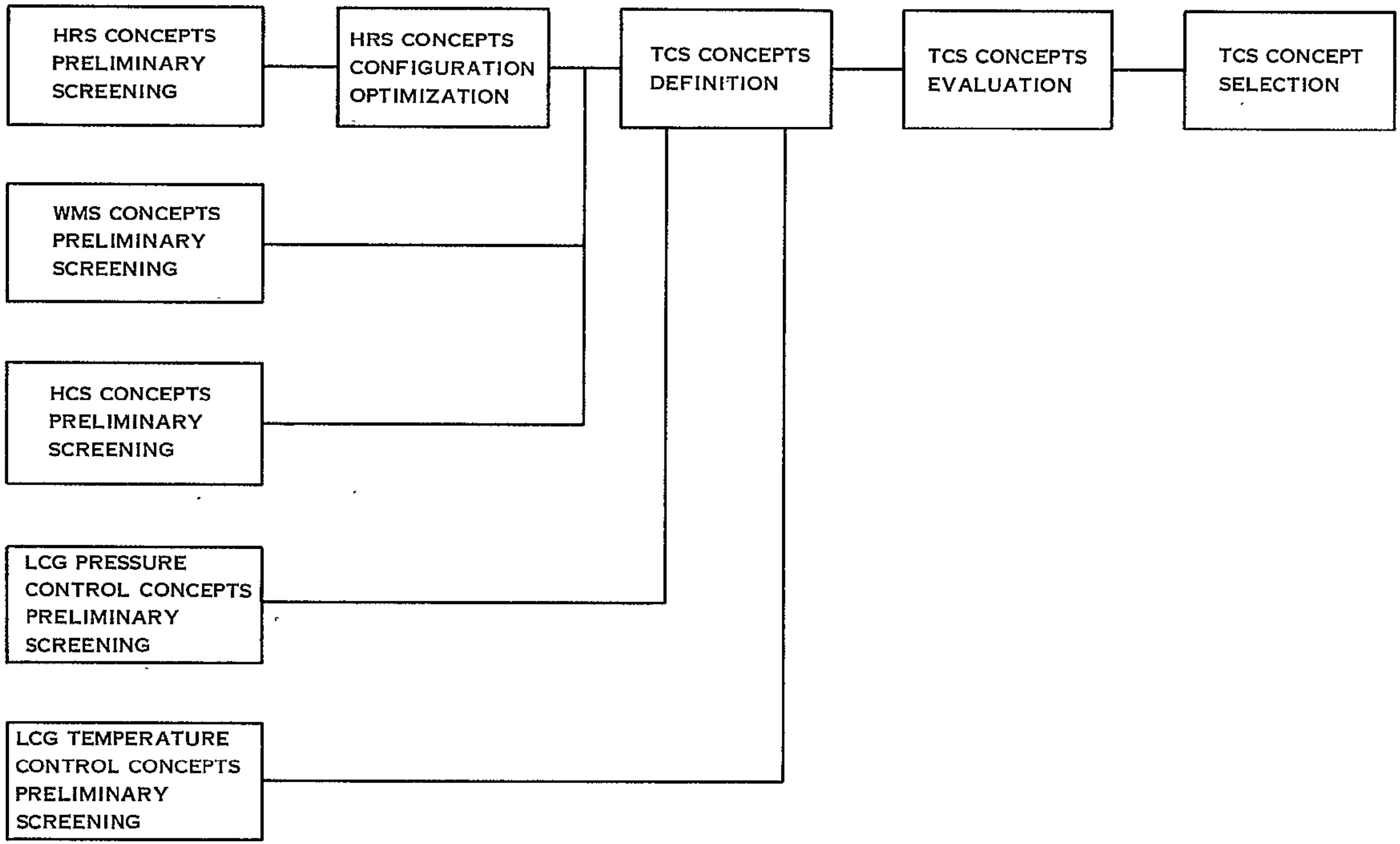


FIGURE 4-2-1. STUDY LOGIC

4.3.1 (Continued)

Relative Criteria

Development/Availability - The technology risk presented by each concept was assessed, and a determination was made about the ability to verify the feasibility of a concept within the limits of the TCS program.

Maintenance - Each concept was evaluated for ease of check out, cleaning, and replacement of limited life items during ground check out and, as applicable, ease of recharge during flight.

4.3.2 Candidate Concepts Definition and Preliminary Screening

Previous studies (references 1 and 2) had identified expendable water heat sinks as the optimum for the Shuttle EVLSS applicaton since the Orbiter vehicle fuel cells generate more water than required by the Orbiter systems, and the extra water can be used as an EVA expendable with no vehicle launch weight penalty.

These studies included significant preliminary design effort which identified three basic types of expendable water heat rejection devices. These are the water boiler, the flash evaporator, and the sublimator. A detailed description of the theory of operation of each of these devices is presented in Appendix B.

During this study, there were four water boilers, six flash evaporators, and three sublimator concepts defined and evaluated. These concepts and the evaluation results are summarized in Table 4-3-1 and are described in detail in Appendix C.

All of the water boilers were eliminated from further consideration due to performance and maintenance problems inherent in their concepts; four of the flash evaporators were eliminated due to inability to meet performance requirements and high technology risk; two of the sublimators were eliminated due to inability to meet performance. The remaining candidates included two spraying flash evaporators; with a hydraulic nozzle or a pneumatic nozzle and the replaceable plate sublimator.

For the two flash evaporator concepts, there are four configurations that could be used: cylindrical, hexagonal, flat plate and conical. These configurations were further evaluated along with the flash evaporator concepts.

4.3.3 HRS Concepts Configuration Optimization Criteria Definition

The HRS concepts configuration optimization was conducted by evaluating alternate approaches on a relative basis considering the following factors:

Life - Each concept was evaluated on the basis of contamination sensitivity, corrosion potential and cyclic endurance limitations.

1) Sutton, J. G., Heimlich, P. F., and Tepper, E. H., "Advanced Extravehicular Protective Systems Study", Hamilton Standard, NASA Contract Report NASA CR 114383; March 1972.
2) Beggs, J. C, et al, "Space Shuttle EVA/IVA Support Equipment Requirements Study", Hamilton Standard Report SP 01T73, April 1973.

TABLE 4-3-1

HRS CONCEPT LISTING AND PRELIMINARY EVALUATION SUMMARY

Concept	Remarks	Viable Candidate
Remote Storage H_2O Boiler with Wick Wetness Sensor Ref. Figure C-2-1	Wetness sensor cannot provide accurate indication of wick condition. Possible to flood unit, resulting in excessive loss of water. Poor operational experience with this type of device. Wicks also require considerable maintenance, which could result in replacement and retest after each flight. The critical interface between the wick and the heat transfer surface requires elaborate testing to verify proper installation. Concepts has a potential for spillage at start up.	No
Remote Storage H_2O Boiler with LCG Delta T Control Ref. Figure C-2-2	Sensing errors are too great and can result in flooding of wick. Wicks also require considerable maintenance which could result in replacement and retest after each flight. The critical interface between the wick and the heat transfer surface requires elaborate testing to verify proper installation. Concept has a potential for spillage at start up.	No
Remote Storage H_2O Boiler with Pressure Feed Ref. Figure C-2-3	Regulator accuracy requirements are too stringent. Control errors can result in flooding. Wicks also require considerable maintenance which could result in replacement and retest after each flight. The critical interface between the wick and the heat transfer surface requires elaborate testing to verify proper installation. Concept has a potential for spillage at start up.	No
Integral Storage H_2O Boiler Ref. Figure C-2-4	There is no procedurally acceptable means to recharge the water boiler. Testing of IR&D unit demonstrated that the only way to prevent flooding during recharge is to use a wick feed. Air inclusion in wick can result in an incomplete charge which is not possible to detect. Wicks also require considerable maintenance which could result in replacement and retest after each flight. The critical interface between the wick and the heat transfer surface requires elaborate testing to verify proper installation. Concept has a potential for spillage at start up.	No

TABLE 4-3-1
(Continued)

Concept	Remarks	Viable Candidate
High Pressure (HP) Hydraulic Nozzle Spray Flash Evaporator Ref. Figures C-2-5 and C-2-7	IR&D design, test and analysis has verified concept meets preliminary screening requirements.	Yes
Low Pressure (LP) Impingement Nozzle Spray Flash Evaporator Ref. Figures C-2-5 and C-2-8	Potential performance problems due to ice build up on pin. Low velocity of the spray droplets could result in ice formation before reaching the heat transfer surface.	No
Pneumatic Nozzle Spray Flash Evaporator Ref. Figures C-2-5 and C-2-9	Concept meets preliminary screening requirements.	Yes
LP Ultrasonic Nozzle Spray Flash Evaporator Ref. Figure C-2-5	Produces atomized fog at low velocity. Water will freeze before reaching heat transfer surface. Ultrasonic device imposes weight, volume and power penalties and would require substantial development for this application.	No
LP Mechanical Atomizing Nozzle Spray Flash Evaporator Ref. Figure C-2-10	Requires development of vacuum compatible high speed motor. Technical risk high. Complexity, weight, volume and power consumption greater than other concepts.	No
LP Rotating Drum Flash Evaporator Ref. Figure C-2-6	Basic concept complex, requiring rotating seal between LCG loop and vacuum and rotating heat exchanger. Won't meet performance as slave water in unit prevents reaching the non-venting mode within five minutes. Also, potential for ice formation within the unit could make it inoperative.	No

TABLE 4-3-1
(Continued)

Concept	Remarks	Viable Candidate
Apollo Type Sublimator (Non Replaceable Plate) Ref. Figure C-2-11	Large slave volume prevents reaching non-venting mode in five minutes, and concept can produce excessive spillage on start up.	No
Replaceable Plate Sublimator Ref. Figure C-2-12	IR&D design, test and analysis verified concept will meet preliminary requirements.	Yes
Low Back Pressure (Litton) Sublimator Ref. Figure C-2-13	Complex feed water distribution configuration. Back pressuring foam prone to self destruction if it becomes saturated with water (turns to ice restricting flow to ambient and over pressures foam). May be difficult to match feed water flow with heat rejection needs. Feed water felt strips will cold flow with time which may upset flow/heat rejection balance. Concept offers no advantages over replaceable plate sublimator.	No

4.3.3 (Continued)

Hardware Cost - The relative nonrecurring and recurring cost for each configuration was assessed based on the complexity of the concept.

EVLSS Weight - The relative weight of the component and package weight for each configuration was assessed.

EVLSS Volume - The relative volume required to package each configuration was assessed.

4.3.4 Configuration/Arrangement Candidate Description and Evaluation

For each basic type of heat rejection subsystem, the following three schematic arrangements were considered.

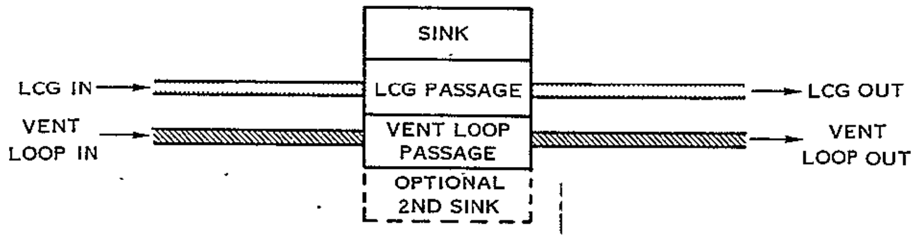
Three-Fluid Heat Exchanger - This concept, shown in Figure 4-3-1, uses a common sink to cool two separate coolant passages. The vent loop is cooled by conduction to the LCG passage which is in turn cooled by conduction to the sink. The heat exchanger could use an optional second sink to provide direct cooling for both coolant passages.

Two Two-Fluid Heat Exchangers - This concept, shown in Figure 4-3-2, uses a sink to directly cool the LCG in the first two-fluid heat exchanger, and then the LCG loop cools the vent loop via a second two-fluid heat exchanger.

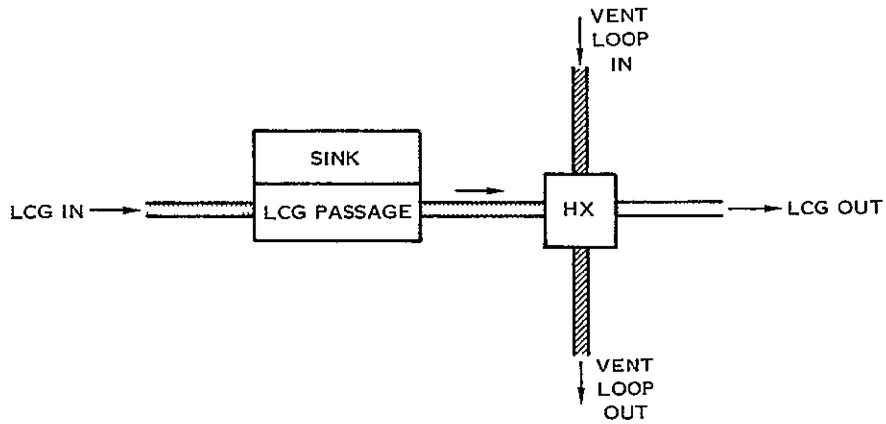
Two Independent Two-Fluid Heat Exchangers - This concept, shown in Figure 4-3-3, uses two sinks which are independently controlled. One sink cools the vent loop; the other sink cools the LCG. This combination, although employing two independent sinks, may be packaged into a single heat exchanger, but the LCG and vent loops are not thermally interconnected. This is the schematic arrangement used in the Apollo backpack sublimator. With this arrangement, cooling of the vent loop by a vehicle umbilical during a no vent mode of operation is not possible; thus, this concept was rejected.

Since the vent loop portion of the HRS is a condensing heat exchanger, a potential for pitting corrosion exists so special consideration was given to meeting the 15-year life requirement. This requirement can be met by either making the heat exchanger of stainless steel or by utilizing an aluminum heat exchanger having a 0.040 inch thick parting sheet. In the case of the three-fluid device, the aluminum heat exchanger is lighter, smaller and cheaper to produce so it was the selected candidate. For the two-fluid vent loop to LCG loop heat exchanger, stainless steel was selected since its small size and number of separating plates negate the advantages of using aluminum.

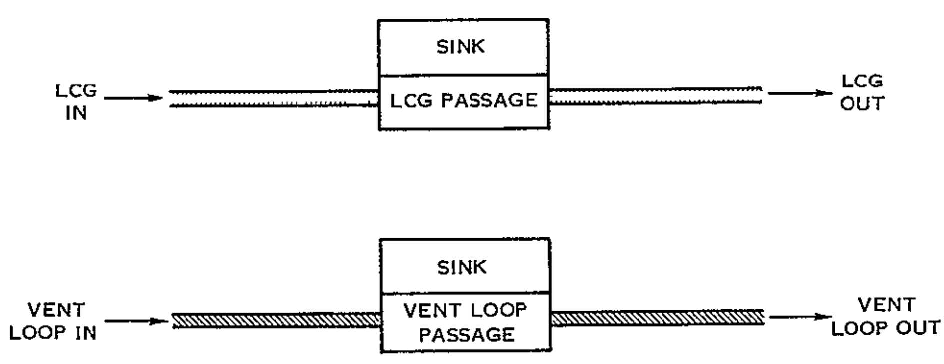
Combining the two viable heat exchanger arrangements with the three HRS candidates and the four alternate flash evaporator configurations resulted in definition of the concepts listed in Tables 4-3-2, 4-3-3, 4-3-4, and 4-3-5. The evaluation consisted of selection of the better flash evaporator nozzle



THREE–FLUID HEAT EXCHANGER
FIGURE 4-3-1



TWO TWO–FLUID HEAT EXCHANGERS
FIGURE 4-3-2



TWO INDEPENDENT TWO –FLUID HEAT EXCHANGER
FIGURE 4-3-3

4.3.4 (Continued)

(Table 4-3-2), the optimum flash evaporator shape (Table 4-3-3), the optimum flash evaporator heat exchanger arrangement (Table 4-3-4) and optimum sublimator configuration (Table 4-3-5). The detail description of each concept considered and of the evaluation results is included in Appendix E. The pneumatic nozzle flash evaporator was found to be non competitive from a weight, volume, and cost standpoint. A cylinder was found to be the most competitive shape for the flash evaporator. A two two-fluid heat exchanger was found to be best for the flash evaporator, while a three-fluid heat exchanger was found to be the most competitive configuration for the sublimator. These two HRS concepts are carried into further TCS level evaluations and are described in further detail in the following paragraphs.

The spraying flash evaporator, with two-fluid heat exchanger, is shown in Figure 4-3-4.

The expendable water is sprayed through a hydraulic nozzle which breaks the liquid stream into droplets forming a hollow cone spray.

These droplets impinge on an aluminum cylindrical heat exchanger surface which is finned at the water droplet impact zone to provide more area for heat transfer. The chamber in which the evaporation takes place is vented to vacuum ambient. This maintains the chamber pressure to a level that promotes droplet evaporation. The water vapor released by the evaporation process exits the chamber through the vent hole.

The LCG flow circulates through eight-parallel passages that are machined into the aluminum surface by a standard screw thread machining process. The heat transfer is accomplished by conduction from the LCG flow through the aluminum wall to the finned droplet impact zone to the vaporizing expendable water. The LCG outlet water temperature is monitored, and the feed water flow through the nozzle is controlled electrically to maintain a constant outlet temperature.

Hamilton Standard IR&D testing and analysis conducted prior to the award of this contract was used to generate flash evaporator weight and volume characteristics as shown in Figure 4-3-5. This in turn was used in the sizing of the unit shown in Figure 4-3-4.

After exiting the flash evaporator, the cooled LCG flow passes to a stainless steel heat exchanger which is shown in Figure 4-3-6. It is utilized as a heat sink to cool the oxygen loop. This stainless steel cross flow unit is a plate-fin design with three oxygen loop passages. Four LCG loop passages make a single pass through the heat exchanger.

The three-fluid sublimator is shown in Figure 4-3-7.

The oxygen loop is cooled by making a single pass in the cross flow direction in a finned passage mounted adjacent to the LCG finned passage. The LCG loop is in turn cooled by feed water sublimation through the porous plate. The rate at which the feed water sublimates is proportional to the heat load imposed by the vent and LCG loops; thus, this device is self-controlling.

TABLE 4-3-2
FLASH EVAPORATOR NOZZLE SELECTION

HRS Concept	Remarks	Viable Candidate
228 Kpa (33 psi) Hydraulic Nozzle Ref. Figures C-2-5 and C-2-7	Least volume and weight approach and meets performance requirements.	Yes
Pneumatic Nozzle Ref. Figures C-2-5 and C-2-9	Imposes a 14.5 Kg (32 lb) and .065 m^3 (4,000 in^3) penalty for gas.	No

TABLE 4-3-3
FLASH EVAPORATOR SHAPE SELECTION

HRS Concept	Remarks	Viable Candidate
Cylindrical - Ref. Figure E-2-1	IR&D design test and analysis has shown that this is a competitive configuration with a high pressure nozzle.	Yes
Hexagonal - Ref. Figure E-2-2	Close to cylinder in volume and weight but more costly to produce.	No
Flate Plat or Conical Ref. Figures E-2-3 and E-2-4	Configuration analysis of flat plate and conical heat exchanger show they offer no significant weight or volume advantage over cylinder while being more costly to produce.	No

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TABLE 4-3-4
FLASH EVAPORATOR HEAT EXCHANGER ARRANGEMENT SELECTION

HRS Concept	Remarks	Viable Candidate
Three-Fluid HX - Ref. Figure E-2-6	Heat transfer characteristics between vent loop and LCG loop impose a significant volume penalty on the flash evaporator. In addition, concept is heavier and more costly to produce than the two two-fluid approach. Concept not considered further.	No
Two Two-Fluid HX Ref. Figures E-2-1 and E-2-5	Least weight, volume and cost approach concept suitable for evaluation at the TCS level.	Yes

TABLE 4-3-5

SUBLIMATOR HEAT EXCHANGER ARRANGEMENT SELECTION

HRS Concept	Remarks	Viable Candidate
Three-Fluid HX - Ref. Figure E-2-8	This configuration is slightly larger than the two-fluid HX approach, but it is lighter and less costly to produce.	Yes
Two Two-Fluid HX Ref. Figures E-2-7 and E-2-5	This configuration is heavier and approximately twice as expensive to produce when compared to the three-fluid HX. Small volume advantage not considered sufficient to warrant weight and cost penalty.	No

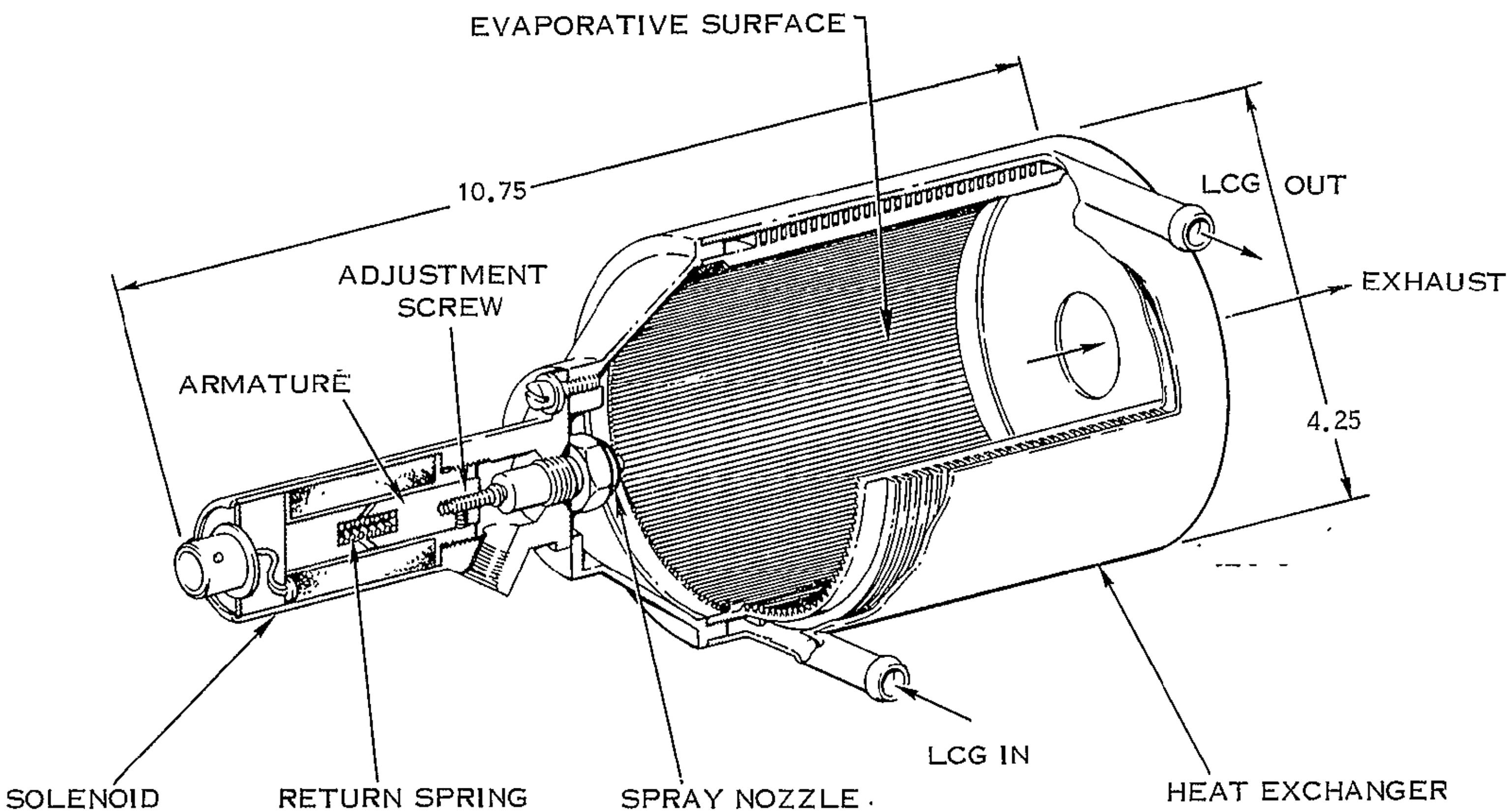


FIGURE 4-3-4
SPRAYING FLASH EVAPORATOR WITH TWO-FLUID HEAT EXCHANGER

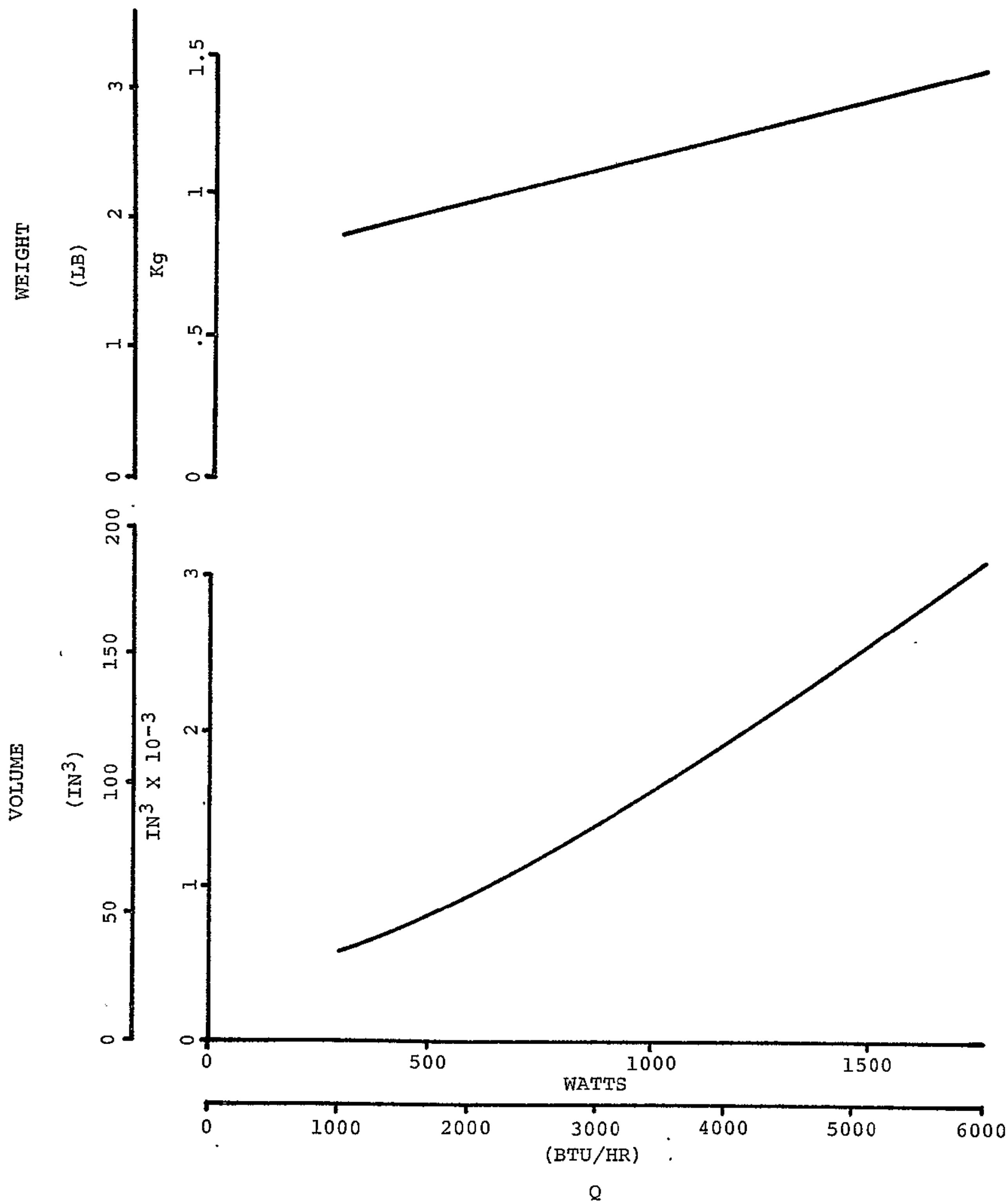


FIGURE 4-3-5

FLASH EVAPORATOR WEIGHT AND VOLUME VS HEAT LOAD

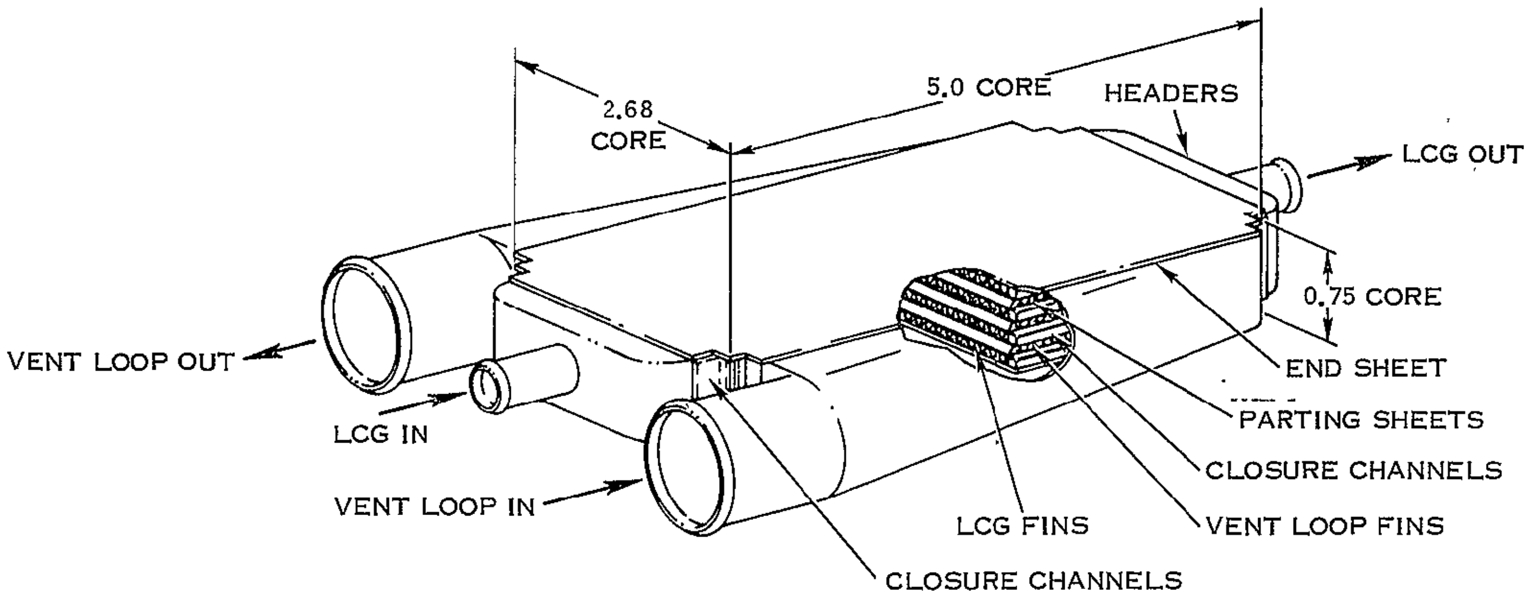


FIGURE 4-3-6

TWO–FLUID STAINLESS STEEL HEAT EXCHANGER

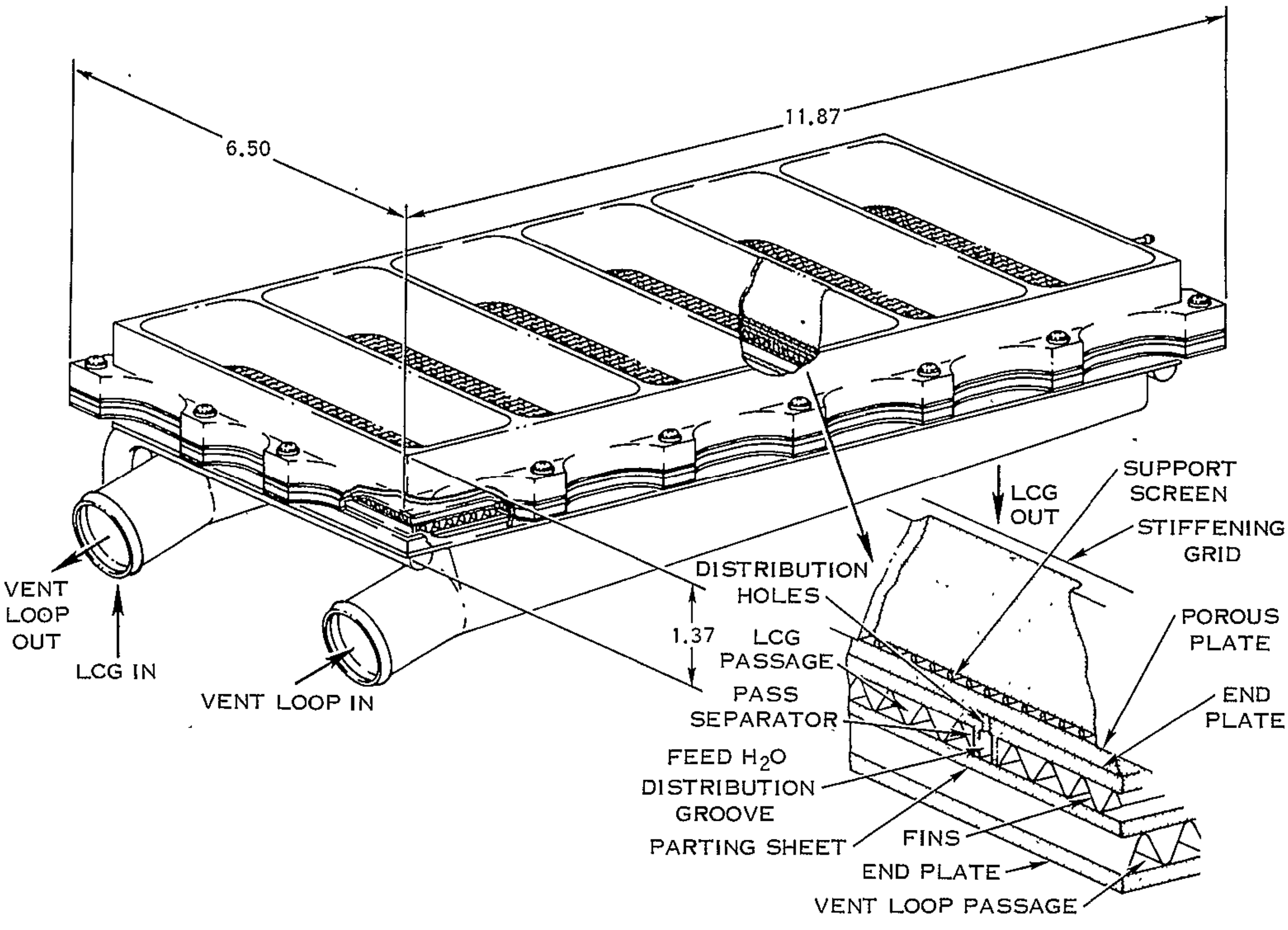


FIGURE 4-3-7
THREE-FLUID SUBLIMATOR

4.3.4 (Continued)

All end sheets, parting sheets, closure bars and the O_2 vent loop inlet and outlet headers are constructed of 0.04 inch thickness aluminum to meet the 15-year life objective.

Hamilton Standard IR&D test and analysis conducted prior to the award of this contract was used to generate the sublimator weight and volume shown in Figure 4-3-8. This figure was in turn utilized to size the evaluation unit.

These two configurations were then combined with other subsystems to form the TCS concepts which were then evaluated at the system level.

4.4 Water Management Subsystem (WMS)

4.4.1 WMS Criteria Definition

The WMS candidate concepts were evaluated first against two absolute criteria, and those found compliant were then rated against three relative criteria. These five criteria are defined below.

Absolute Criteria

Safety - Each concept was evaluated to determine if there were any hazards which could not be eliminated. Specifically, the concept could not present a toxicty hazard, it had to comply with the Apollo fire and explosion requirements, and a component failure could not result in gross vent loop leakage.

Performance - Each WMS candidate had to be capable of meeting the following performance requirements.

- It must be capable of accepting repetitive full water changes at 248 KPa (36 psia) saturated with nitrogen.
- It must be possible to prove zero "g" operation in a one "g" gravity field.

Relative Criteria

Development/Availability - The technology risk presented by each concept was assessed, and a determination was made about the ability to verify the feasibility of a concept within the limits of the TCS program.

Gross Vehicle Launch Weight - The relative vehicle launch weight considering the impact of two EVLSS's, vehicle support hardware weight and vehicle support power penalty was assessed for each concept.

EVLSS Volume - The relative volume required to package each configuration was assessed.

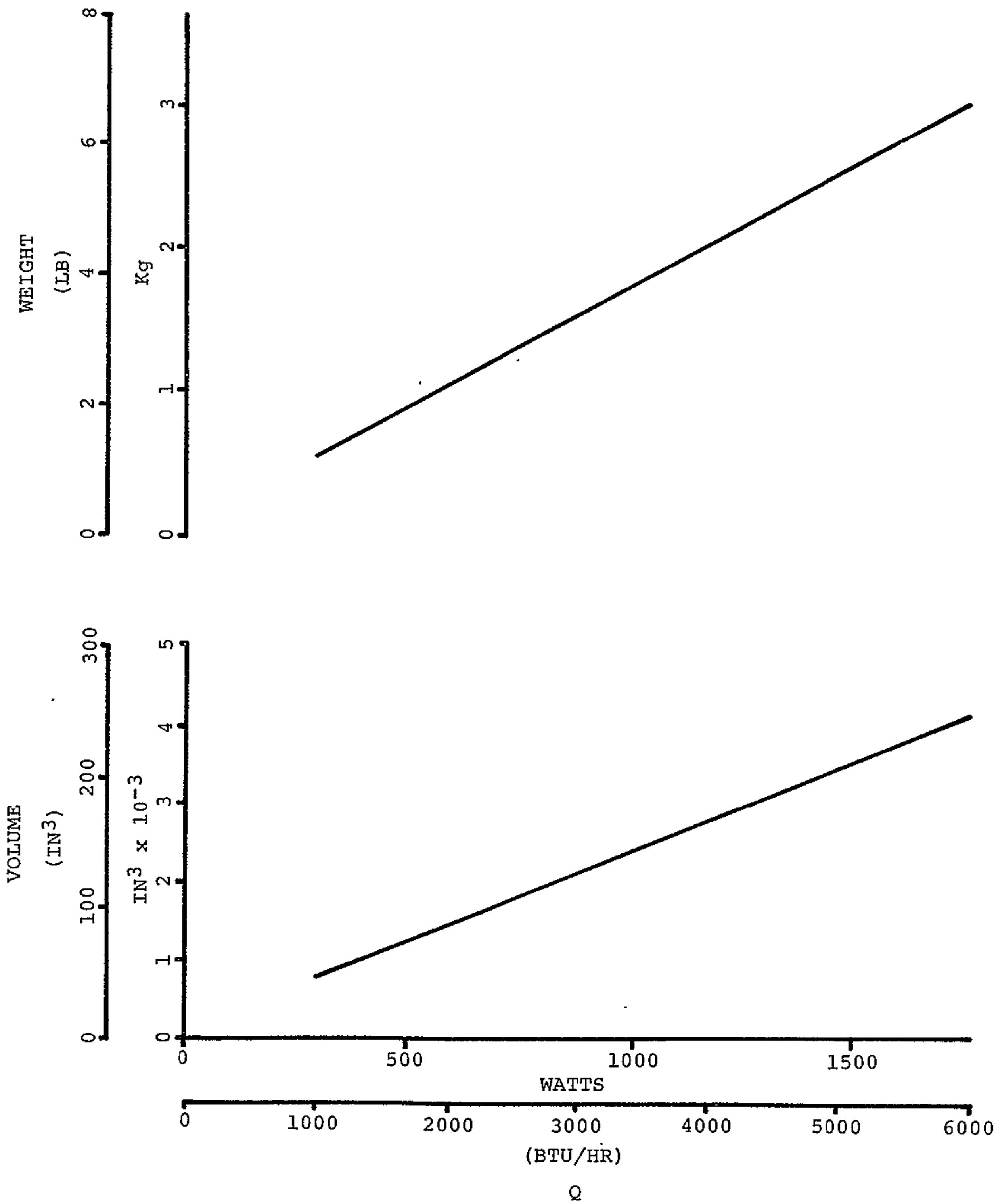


FIGURE 4-3-8

SUBLIMATOR WEIGHT AND VOLUME VS HEAT LOAD

4.4.2 WMS Concept Definition and Preliminary Screening

Thirteen WMS concepts were considered. The evaluation results are summarized in Table 4-4-1 and are presented in detail in Appendix F. All but three of the concepts were eliminated due to failure to comply with safety or performance requirements, or by being non competitive from a weight or volume standpoint.

The three remaining concepts were:

- Bubble Expansion Tank
- High Pressure Water Storage
- Bladder Storage with Pressure Regulator

The following is a description of the three viable WMS candidates.

Bubble Expansion Tank System (Figure 4-4-1) - This concept represents an approach in which a WMS is designed to be compatible with gas saturated water which eliminates the procedures and equipment needed for water deaeration. Following the recharge sequence, the reservoir will contain water and gas bubbles pressurized to the same level as the vehicle water supply system. In this concept, the reservoir is oversized to accommodate the volume of the gas bubble from a single water recharge: that is, the gas that can come out of solution at one atmosphere (originally pressurized) to 248 Kpa (36 psia) is 1.6×10^{-4} m^3 (10 in^3) for a 3.6 Kg (8.0 pound) charge of water. This is conservative because the gas theoretically goes back into solution at the completion of charging.

The bubble expansion tank allows the gas to expand to the operation pressure of the WMS. For a 3.6 Kg (8 pound) capacity primary tank, the expansion tank must be approximately 69×10^{-4} m^3 (43 cubic inches) (for a 37.6 KPa (4.0 psia) feed water circuit pressure). This concept permits separated water storage between the reservoir and the bladder and provides a constant regulated pressure for feed water supply to the HRS.

Prior to recharging the reservoir, the water within the bladders of the reservoir and the bubble tank are drained to the vehicle waste management system. This imposes no vehicle penalty since the waste management system already has the capacity to handle this water.

High Pressure Water Storage (Figure 4-4-2) - This concept avoids the problem of having free gas in the reservoir by storing the water at a pressure above the vehicle fill pressure. During EVLSS recharge, a relief valve maintains the reservoir pressure slightly below the vehicle water supply pressure. This minimizes the quantity of gas evolving during the recharge sequence. A check valve in the fill line prevents the possibility of back flow.

During operation, the EVLSS O_2 supply pressure source pressurizes the stored water at its saturation pressure (the vehicle supply pressure).

TABLE 4-4-1
WMS CONCEPT LISTING AND PRELIMINARY SCREENING SUMMARY

WMS Concept	Remarks	Viable Candidate
Hydrophylic/Hydrophobic Screen Separator Ref. Figures F-2-1 and F-2-2	Deaeration to 25.5 KPa (3.7 psia) requires vacuum penetration of cabin which is undesirable. Deaeration of any higher pressure requires use of some other means to compensate for gas released when operating pressure drops to 25.5 KPa (3.7 psia). Hardware required to assure the venting of the gas is complex and the device is subject to elaborate servicing procedures.	No
Centrifugal Deaerator Ref. Figure F-2-3	Hardware and operational procedures complex. System is gravity sensitive and rotating mass of water could impart gyroscopic forces on astronaut interferring with mobility.	No
Permeation through Bladder Ref. Figure F-2-4	Requires vacuum penetration to cabin which is undesirable. Diffusion of gas from water through bladder to vacuum difficult to predict.	No
Drive Gas out of Solution with Heat - Ref. Figure F-2-5	Approximately 15 lb weight impact on vehicle which is significantly greater than other acceptable approaches. Adds complexity of heater, temperature controller and head exchanger to vehicle.	No
Bubble Expansion Tank Ref. Figure F-2-7	Meets all screening criteria.	Yes
High Pressure Storage Ref. Figure F-2-8	Meets all screening criteria.	Yes

TABLE 4-4-1
(Continued)

WMS Concept	Remarks	Viable Candidate
Zero "G" Tank Ref. Figure F-2-9	Cannot verify zero "g" operation in one "g". The acceleration forces produced when the astronaut moves are sufficient to overcome the surface tension forces which hold the water in an acceptable location.	No
Oversize Tank to Accommodate all Gas Evolved during Six Recharges - Ref. Figure F-2-10	Imposes unacceptable volume penalty.	No
Scavenge Gas with Chemicals	Scavenging chemicals are potentially toxic and precipitates could interfer with performance.	No
Bladder Storage with Water Pressure Regulator Ref. Figure F-2-10	Meets all screening criteria.	Yes
Replaceable H_2O Tanks Ref. Figure F-2-11	Weight impact of 6.8 Kg (15 pounds) per crewman EVA plus excessive volume penalty for storage.	No
Obtain Water Upstream of Potable Water Tank (Add Check Valves to Vehicle Between Fuel Cell and Tanks) Ref. Figure F-2-12	Approach is feasible but not compliant with study groundrules.	No
Use Vehicle Sublimator Water Ref. Figure F-2-13	Requires addition of solenoid shutoff valve and gas separator to vehicle and requires penetration of cabin wall which is undesirable approach offers no advantage over obtaining water upstream of potable water tank.	No

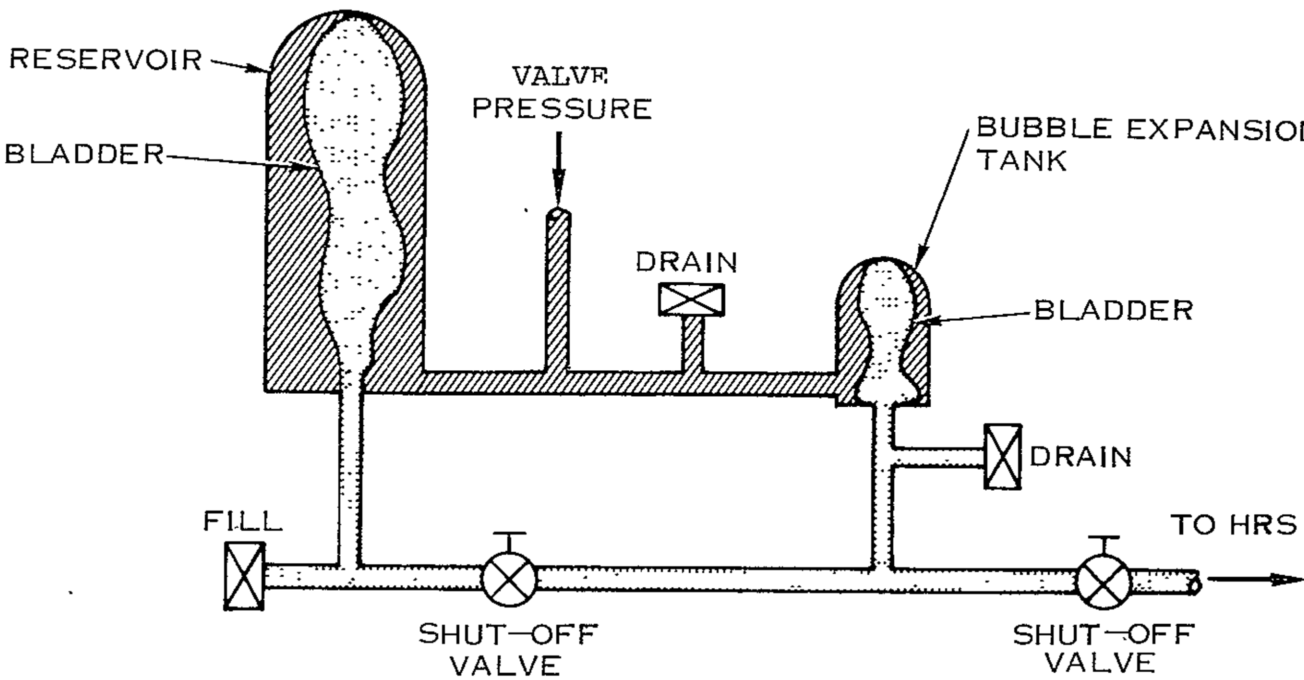


FIGURE 4-4-1
BUBBLE EXPANSION TANK WMS CONCEPT

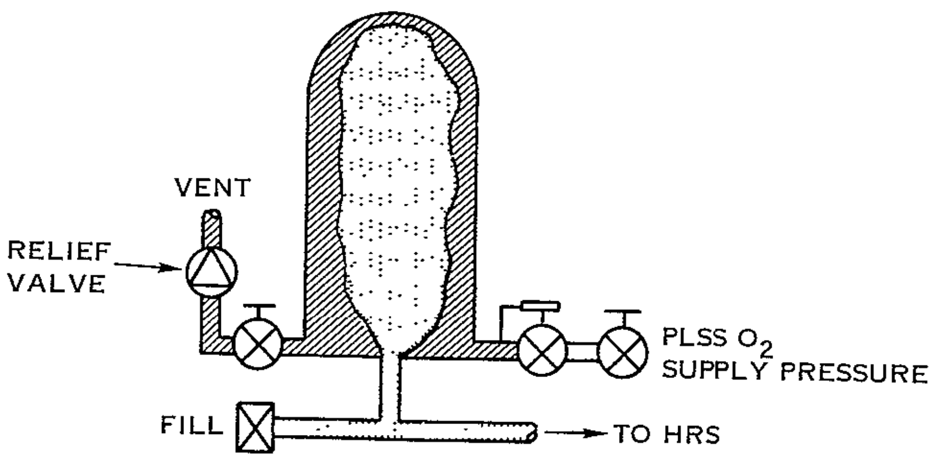


FIGURE 4-4-2
HIGH PRESSURE WATER STORAGE WMS CONCEPT

4.4.2 (Continued)

Bladder Storage with Pressure Regulator (Figure 4-4-3) - In this system, the reservoir is charged with the saturated water. When the system is activated, the free gas in the water maintains the reservoir outlet pressure above 27.6 KPa (4 psi) for approximately the first hour of operation. The water regulators in the line to the HRS maintain the HRS inlet pressure at 27.6 KPa (4 psi) during this period of time. The water and gas remaining in the bladder after a mission is drained prior to recharge to minimize the reservoir size. This system is only compatible with the sublimator since the flash evaporator requires a pressure above 206 KPa (30 psi).

The three WMS concepts described above are used to define the TCS concepts for final evaluation.

4.5 Humidity Control Subsystem (HCS)

4.5.1 Criteria Definition

The HCS candidates were evaluated first against two absolute criteria, and those found compliant were then rated against three relative criteria. These criteria are described below and are similar to those used for the WMS evaluation.

Absolute Criteria

Safety - Each concept was evaluated to determine if there were any hazards which could not be eliminated. Specifically, the concept could not present a toxicty hazard, it had to comply with the Apollo fire and explosion requirements, and a component failure could not result in gross vent loop leakage.

Performance - Each HCS candidate had to be capable of meeting the following performance requirements.

- It must prevent or be insensitive to condensate slugging.
- It must be possible to prove zero "g" operation in a one "g" gravity field.

Relative Criteria

Development/Availability - The technology risk presented by each concept was assessed, and a determination was made about the ability to verify the feasibility of a concept within the limits of the TCS program.

Gross Vehicle Launch Weight - The relative vehicle launch weight considering the impact of two EVLSS's, vehicle support hardware weight and vehicle support power penalty was assessed for each concept.

EVLSS Volume - The relative volume required to package each configuration was assessed.

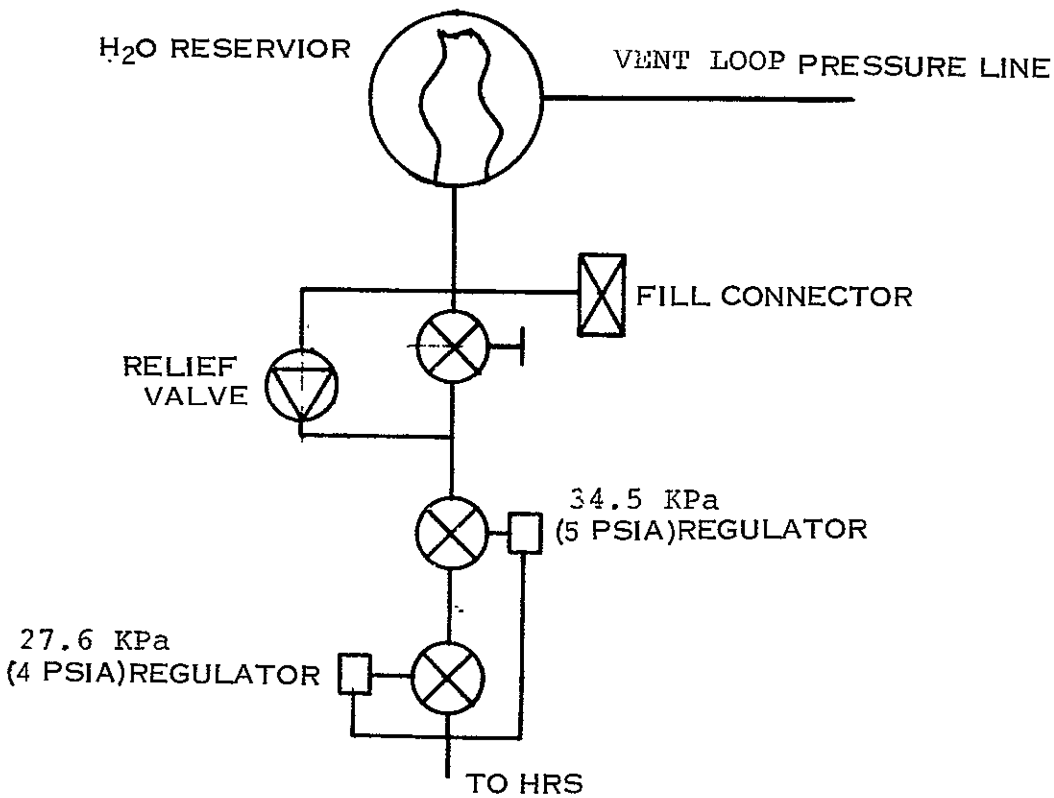


FIGURE 4-4-3
BLADDER STORAGE WITH PRESSURE REGULATOR WMS CONCEPT

4.5.2 HCS Candidate Concept Definition and Evaluation

The candidate Humidity Control Subsystem utilized one or more of the following water separating devices.

Rotary Separator (Figure 4-5-1) - The rotary separator consists of a shaft mounted drum assembly, an impact pitot and a housing to encapsulate the drum. The rotational motion of the drum induces gas/liquid separation. Entrained moisture in the incoming gas stream is forced by centripital acceleration into a trough at the outer periphery of the drum, and the gas stream returns to the vent loop. The pressure at the pitot is the sum of the pressure energy due to water impacting the pitot plus the static pressure developed by rotating the water in the drum. When the water pressure in the pitot exceeds the cracking pressure of a back pressure valve located in the outlet line, the water is pumped into the storage container.

Fan Separator (Figure 4-5-2) - The fan separator is basically a rotary separator with a fan rotor mounted on the same drive shaft.

Elbow Wick Separator (Figure 4-5-3) - The elbow wick separator consists of a bladder, a sponge-like wick and a housing containing inlet and outlet ducts, a drain line and a pressure port. The flow passage through the wick makes several turns to induce water separation from the gas stream by momentum change. The separator permits draining of the condensate at the end of each EVA by pressurizing the bladder to squeeze the wick. This is accomplished by closing valves in the inlet and outlet ducts, connecting a drain fitting to the drain line and pressurizing the back side of the bladder through the pressure port. After draining, the drain fitting is disconnected, the inlet and outlet duct valves are opened and the pressure port is vented to ambient.

Elbow Scupper (Figure 4-5-4) - The elbow scupper consists of an elbow, an O_2 outlet duct and a water duct. The scupper isolates and traps condensate from the gas stream by a change in momentum imposed by turning the flow in the elbow. The water free gas is returned to the vent loop via the O_2 outlet duct. The separated water collects in an annulus where it and approximately 5% of the O_2 is transferred to a second separating device for further processing.

Slurper (Figure 4-5-5) - The slurper consists of a series of bleed holes located within the outlet passage of the condensing circuit of the heat exchanger and are manifolded to a common header. The slurper header pressure is maintained below the condensing circuit pressure; thus, when water condenses and blocks the bleed holes, the pressure differential across the holes draws the water into the manifold which is connected to a second separating device for further processing.

Absorbtion by a Desiccant (Figure 4-5-6) - This device consists of a desiccant container filled with silica gel and a cooling coil. The gas and free water is introduced at one end of the bed and as the gas passes through the bed, the water is absorbed by the silica gel. The heat of absorption is removed by the cooling water.

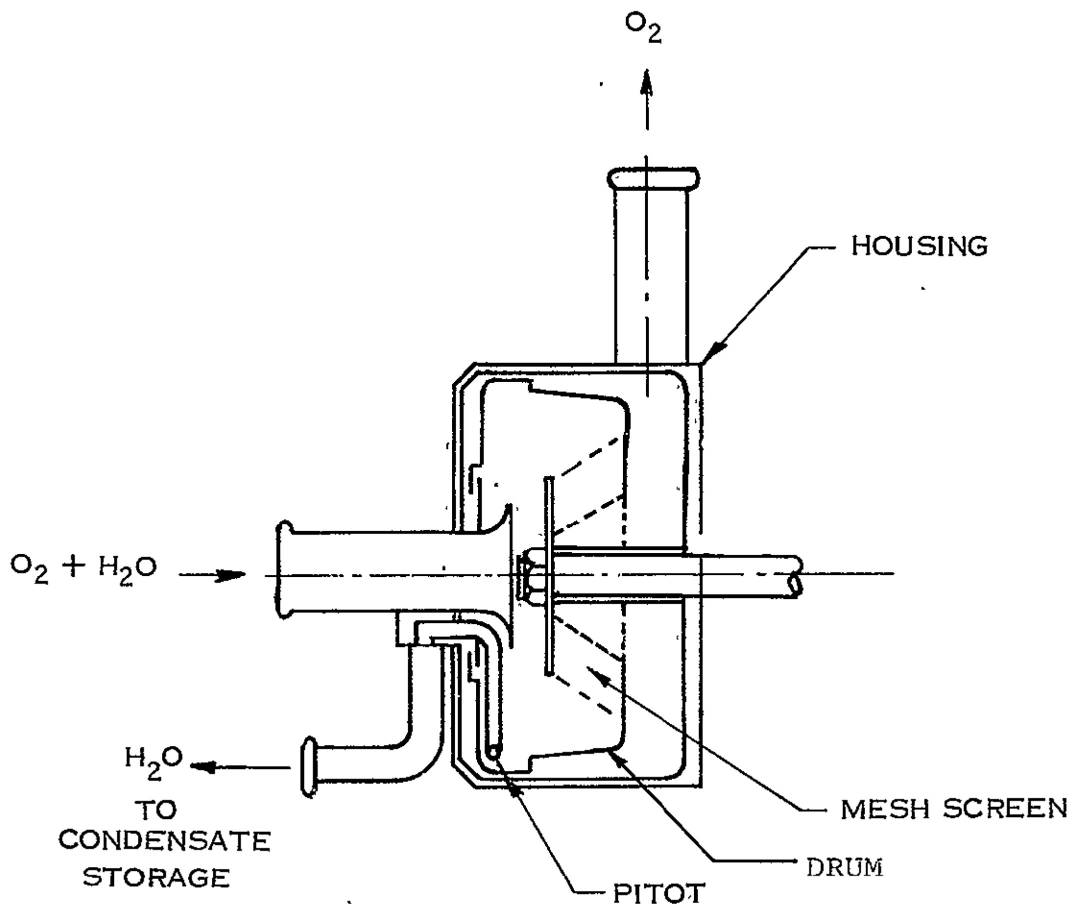


FIGURE 4-5-1
ROTARY SEPARATOR

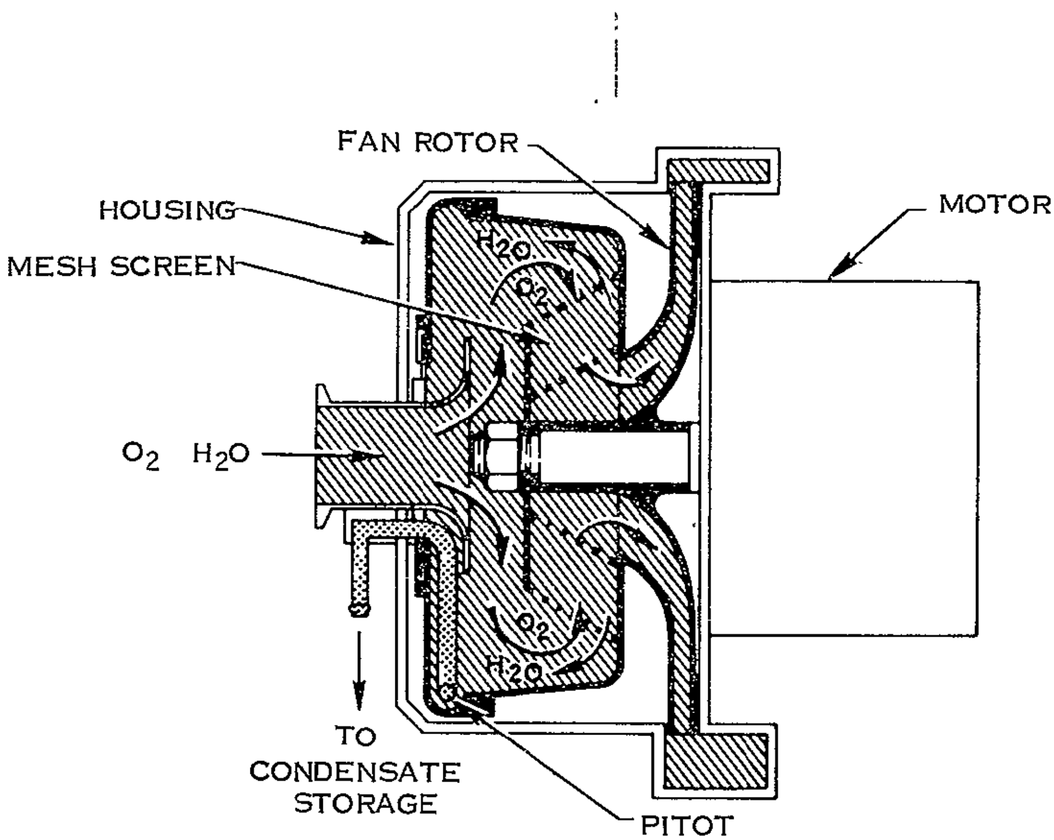
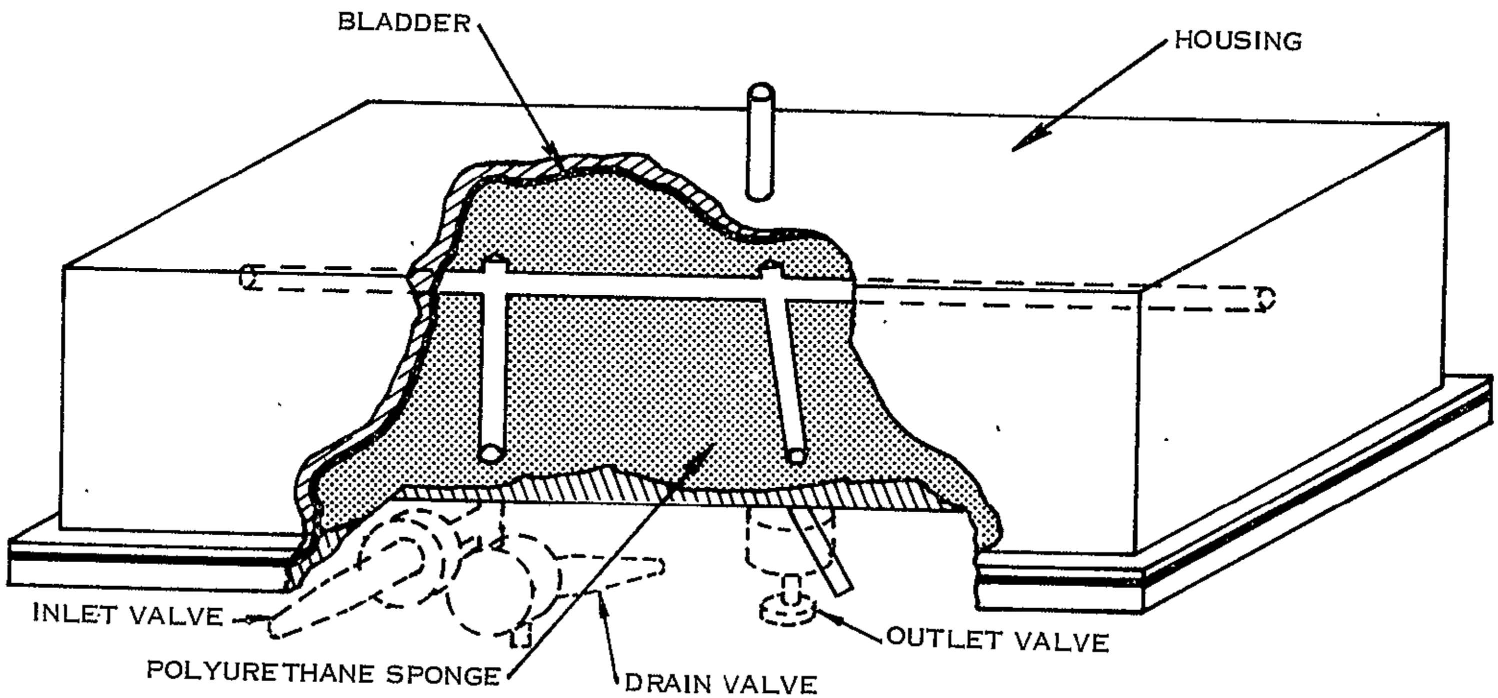


FIGURE 4-5-2
FAN SEPARATOR



WICK SEPARATOR

FIGURE 4-5-3

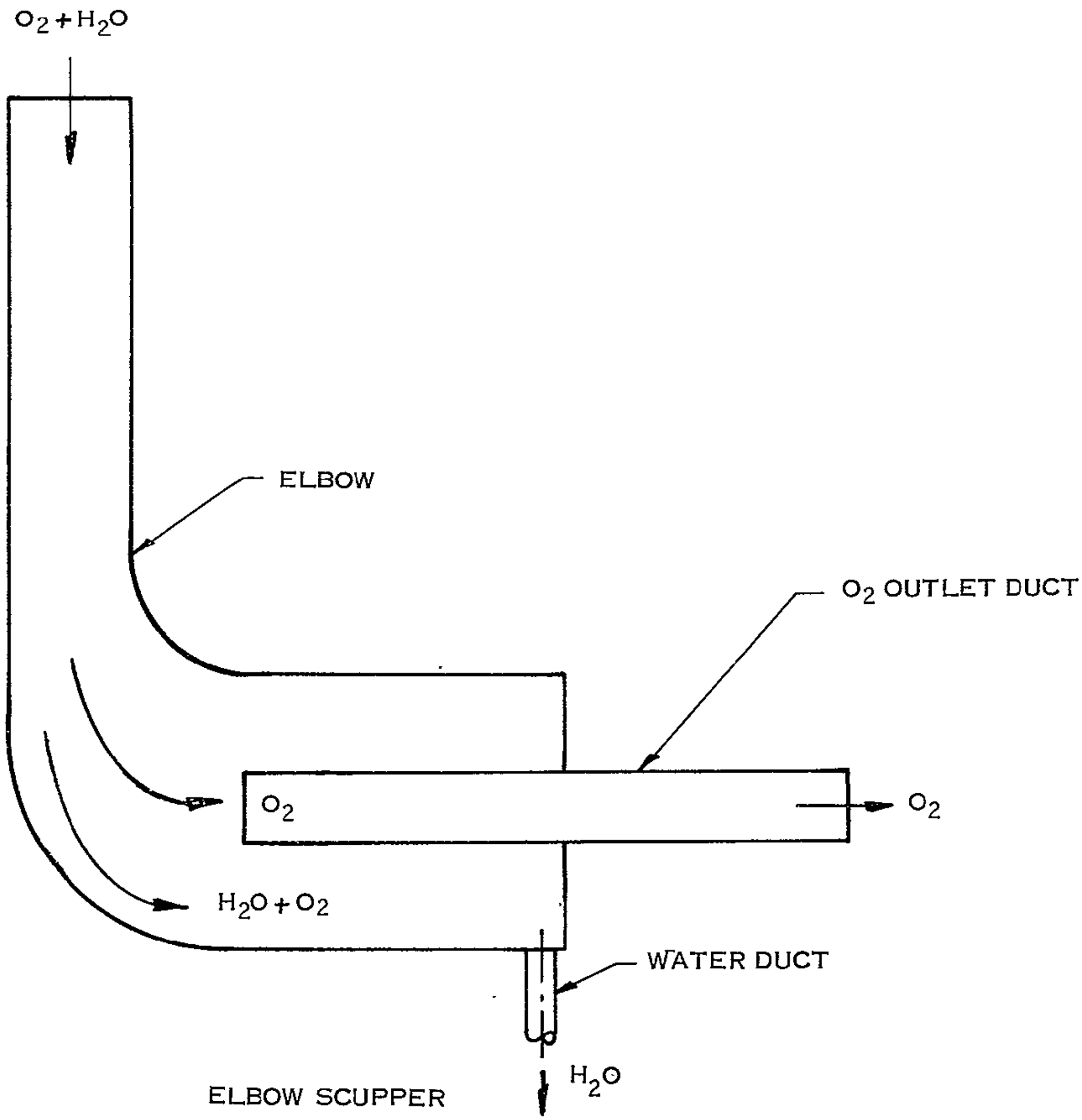
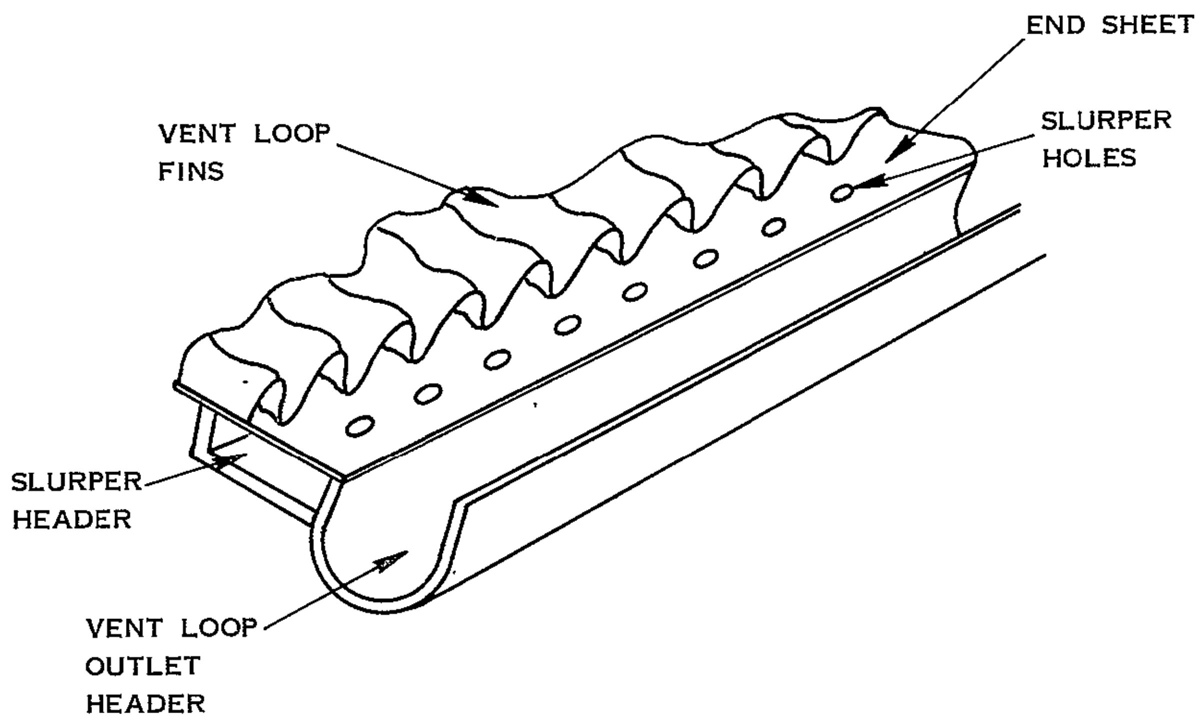


FIGURE 4-5-4
SIMPLIFIED ELBOW SCUPPER



SLURPER

FIGURE 4-5-5

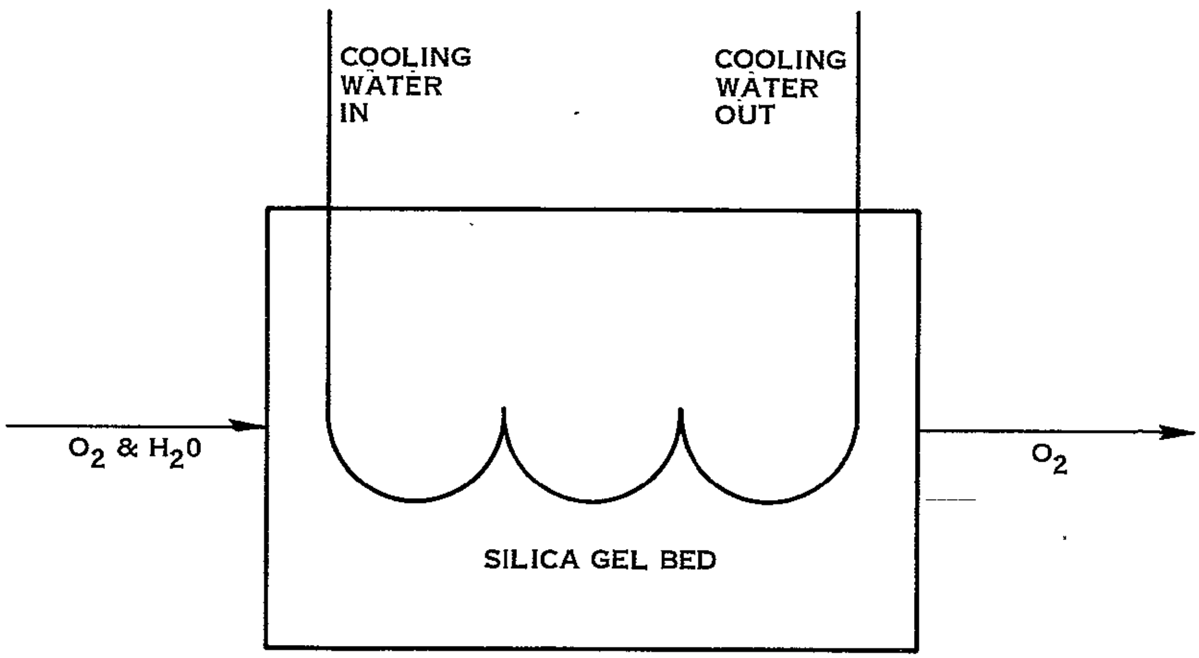


FIGURE 4-5-6. ABSORBTION BY A DESICCANT

4.5.2 (Continued)

These six water separating devices were combined to form the following nine Humidity Control Subsystems.

Single Stage Motor/Rotary Separator (Figure 4-5-7) - In this concept, the gas stream is temperature and humidity controlled in the condensing heat exchanger. Entrained mositure in the gas stream leaving the heat exchanger is removed by the motor rotary separator and pumped to the HRS feed water circuit for use as expendable. The relief valve prevents gas from being transferred with the condensate. Gas leaving the separator is returned to the O_2 ventilation circuit.

Single Stage Fan Separator - This concept is identical to the single stage motor rotary separator except that the fan is the prime mover for the vent loop gas stream as well as the separator.

Single Stage Wick Separator (Figure 4-5-8) - This figure shows a TCS which utilizes the previously described single stage elbow wick separator. In this system, the entrained condensate is removed from the primary gas stream and stored in the wick sump for the duration of the EVA.

First Stage Scupper/Second Stage Fan/Separator (Figure 4-5-9) - With this system, the condensate is separated from the primary gas stream by the scupper and is drawn from the scupper by the delta P generated by the fan separator. The water is then separated from the secondary gas stream by the fan separator and is pumped into the HRS feed water circuit through a relief valve which prevents gas inclusion in the separated water.

First Stage Scupper/Second Stage Rotary Separator (Figure 4-5-10) - This concept is similar to the previous concept except that the fan separator is replaced by a rotary separator with gas outlet located upstream of the fan. This provides the pressure differential necessary to force the flow of the gas and water mixture to the rotary separator.

First Stage Scupper/Second Stage Wick Storage (Figure 4-5-11) - The first stage of this concept is the same as the previous concept with the elbow scupper separating the condensed water from the gas stream, and the fan providing the pressure differential required to force the water to the second stage. The second stage is similar to the single stage elbow wick separator concept except that the flow path through the separator is smaller as it only requires 5% of the main stream flow.

First Stage Slurper/Second Stage Motor/Rotary Separator (Figure 4-5-12)

In this system, the secondary gas loop connects the slurper manifold to the upstream side of the fan to provide the required pressure differential across the slurper. The water drawn from the slurper passes to the motor rotary separator which delivers the condensate to the WMS for use as expendable water for the HRS.

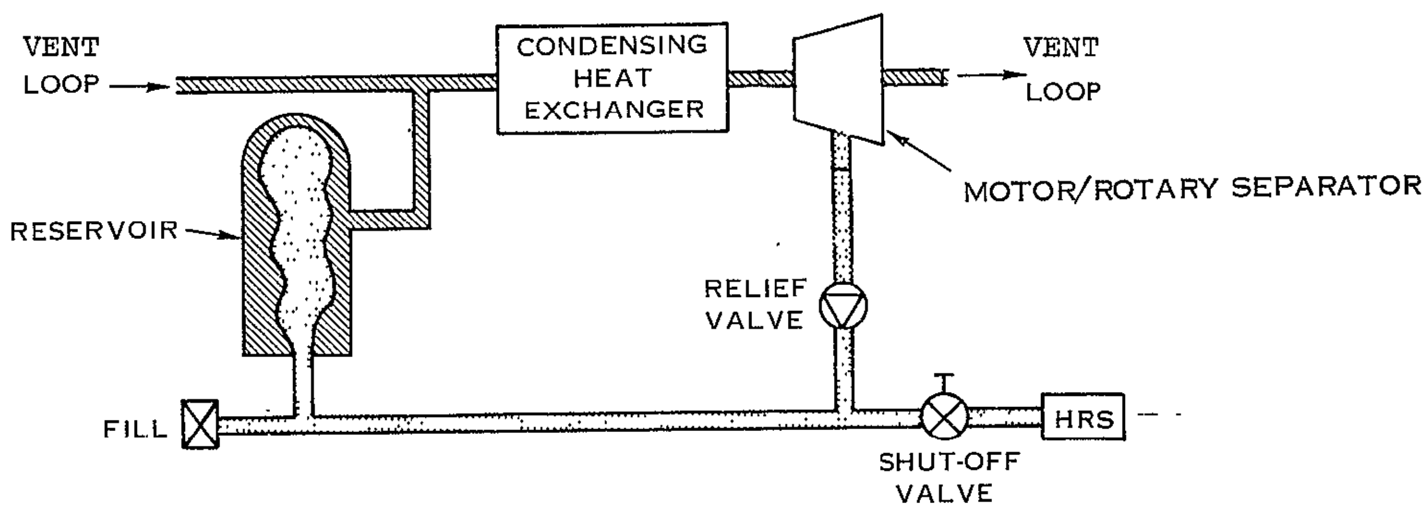
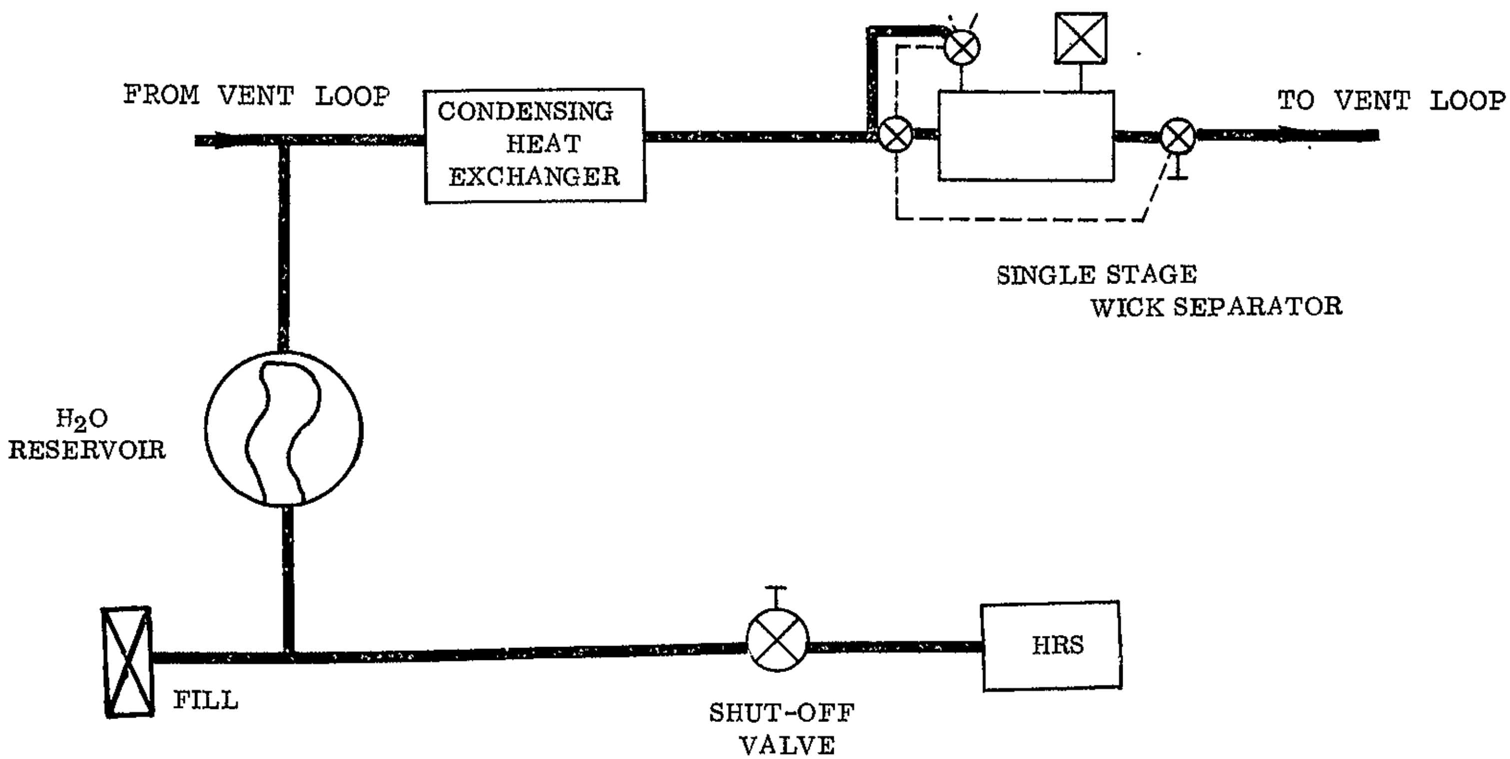
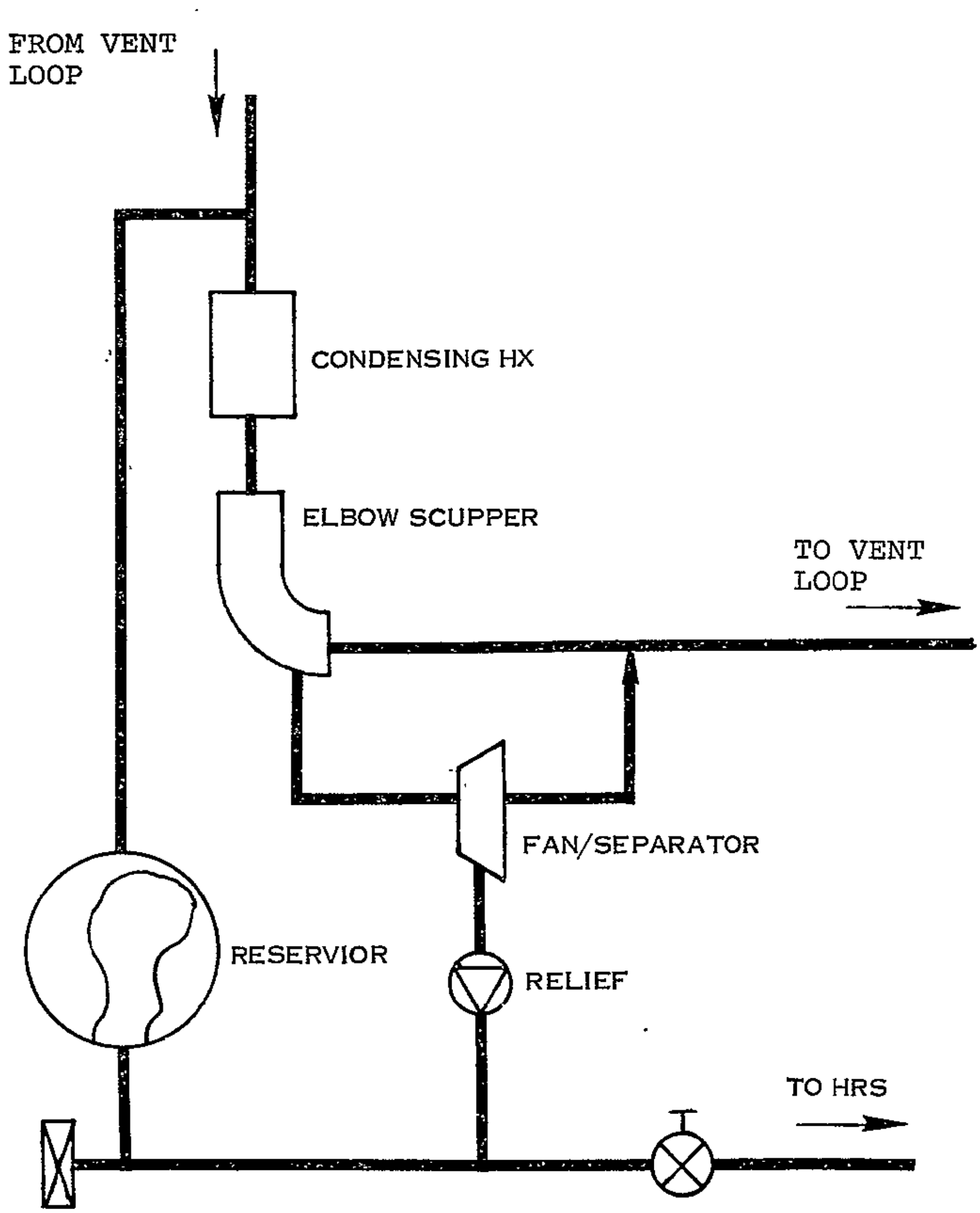


FIGURE 4-5-7
SINGLE STAGE MOTOR/ROTARY SEPARATOR



SINGLE STAGE ELBOW WICK SEPARATOR

FIGURE 4-5-8



FIRST STAGE SCUPPER/2ND STAGE FAN/SEPARATOR
FIGURE 4-5-9

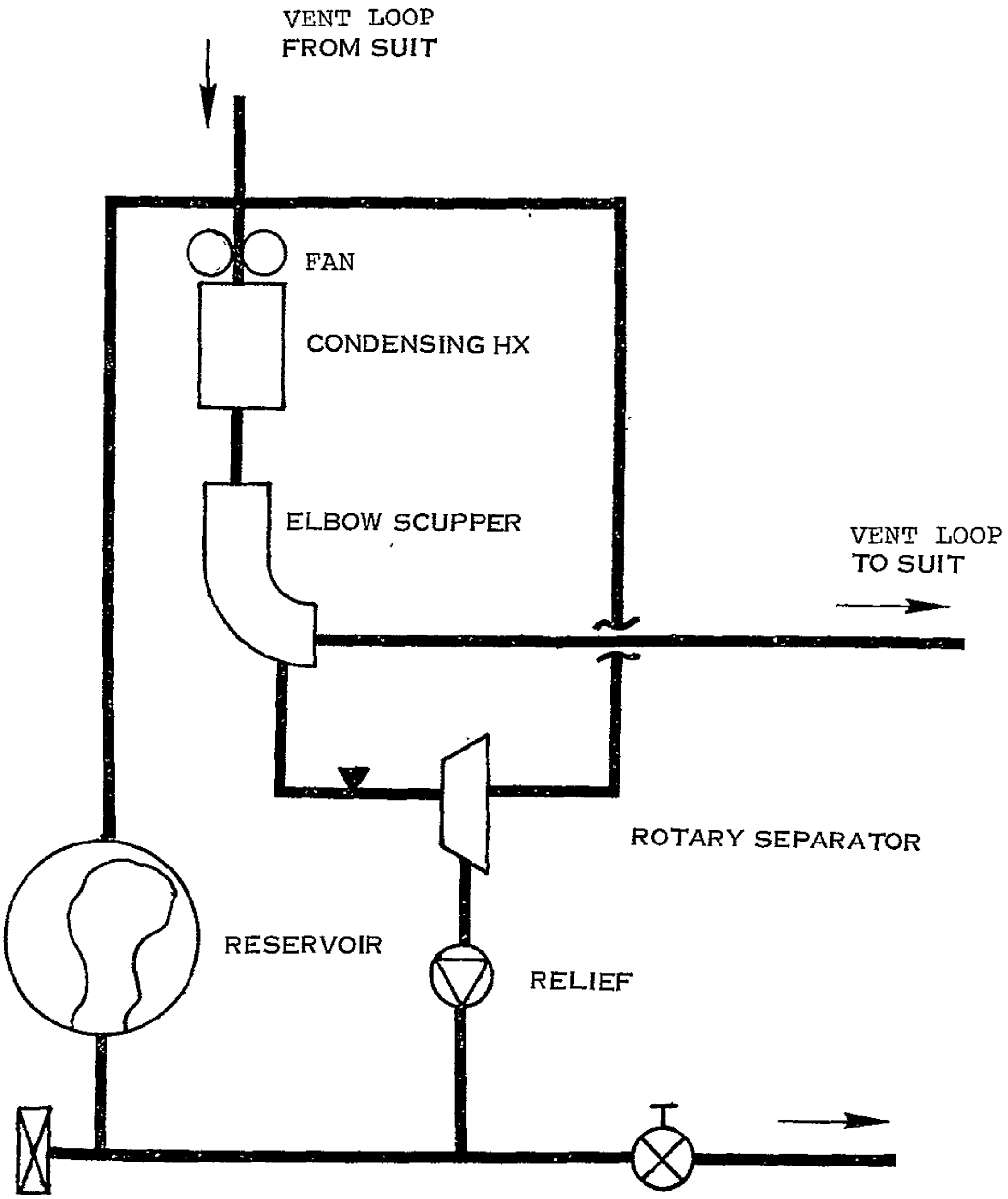
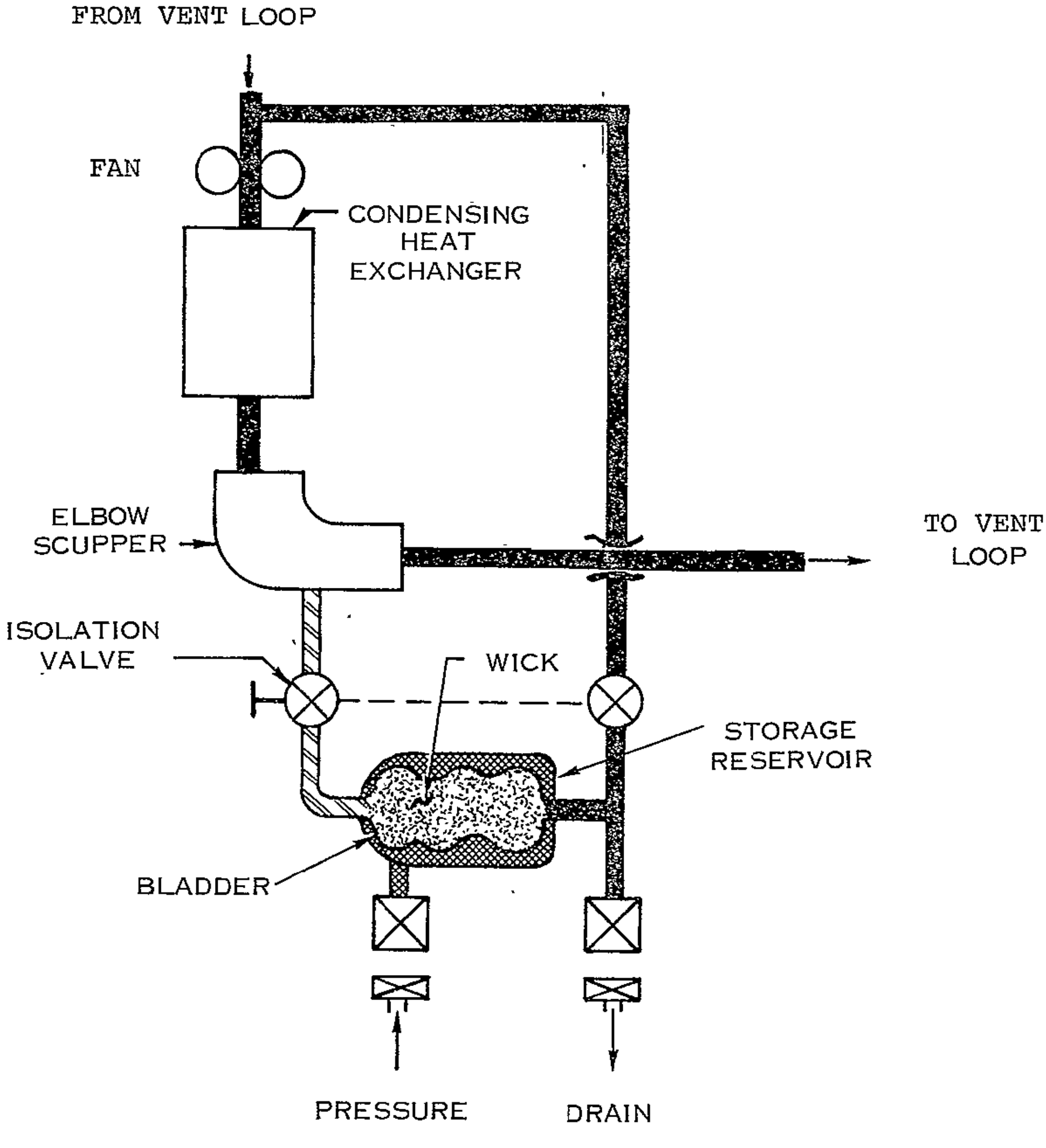


FIGURE 4-5-10
FIRST STAGE SCUPPER/2ND STAGE ROTARY SEPARATOR



FIRST STAGE SCUPPER, SECOND STAGE WICK STORAGE
FIGURE 4-5-11

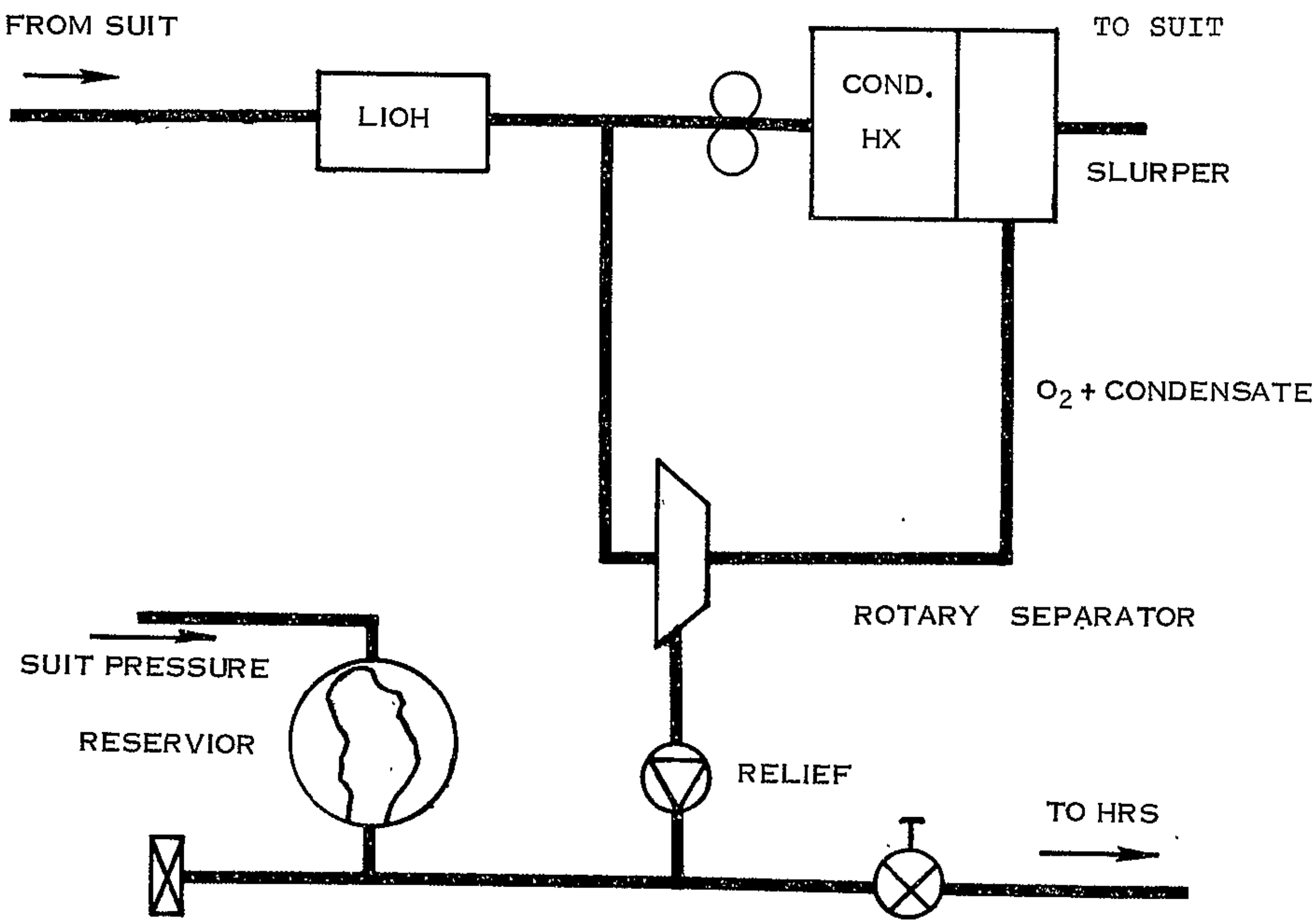


FIGURE 4-5-12
FIRST STAGE SLURPER/2ND STAGE ROTARY SEPARATOR

4.5.2 (Continued)

First Stage Slurper/Second Stage Wick Separator (Figure 4-5-13) - This concept is similar to the previous concept except that a wick separator and storage device similar to the single stage elbow wick separator replaces the rotary separator.

Desiccant (Figure 4-5-14) - In this system, a silica gel bed is located downstream of the CO_2 subsystem to remove the water generated by the man and by the LiOH reaction with CO_2. A bypass valve is required to maintain the system outlet dew point at an acceptable level. The HRS is located downstream of the desiccant to cool the gas exiting from the bed.

The evaluation which is summarized in Tables 4-5-1 and 4-5-2 resulted in the elimination of only the first stage fan separator and desiccant systems with the remaining systems requiring evaluation at the system level.

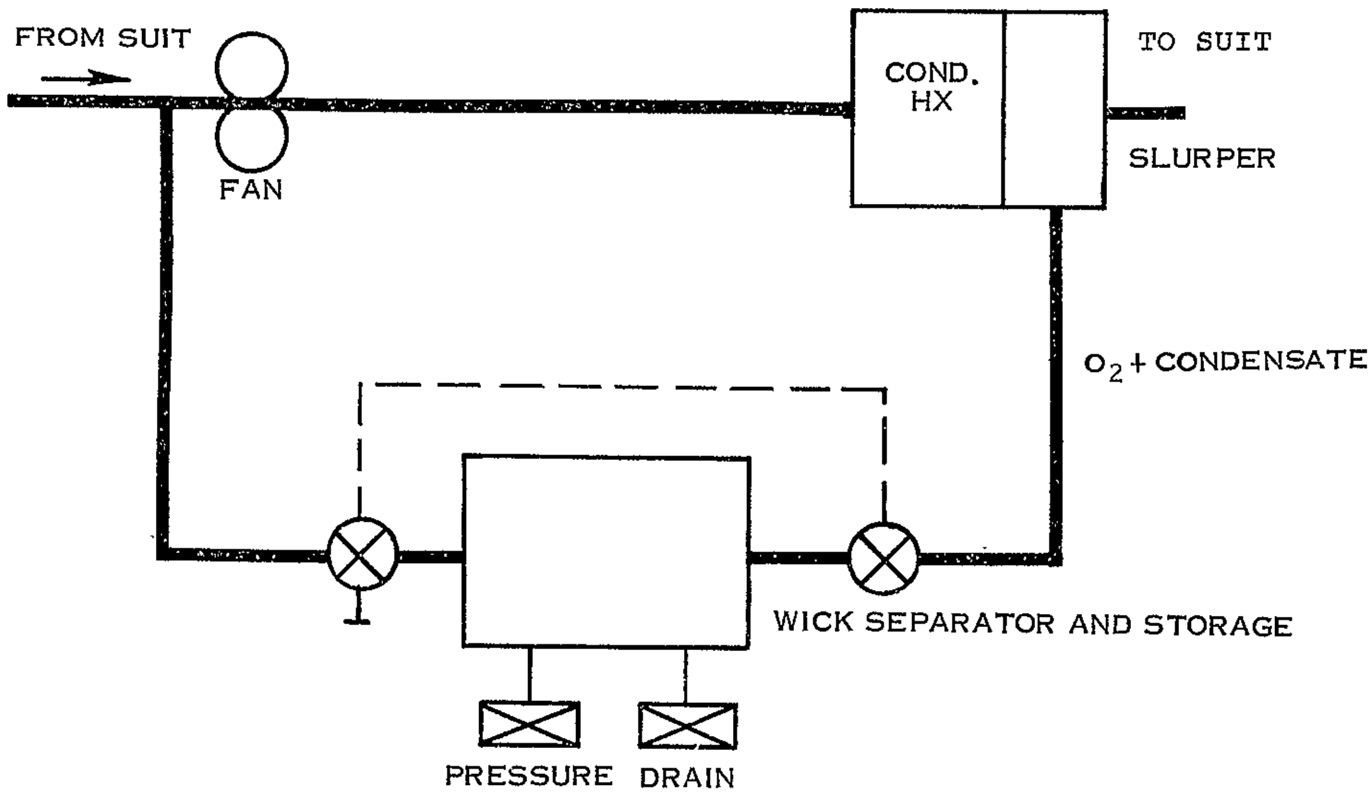
As shown in Tables 4-5-1 and 4-5-2, all nine concepts were compliant with the absolute requirements and were competitive from a development/availability standpoint.

In order to properly assess the weight and volumes of the remaining HCS candidates, it was necessary to accurately size the wick separator and to determine the optimum means of driving the rotary devices.

The wick separator design required the use of a wick material with elastic recovery properties as well as good wicking and capacity characteristics. Previously, wick materials did not have good elastic properties; therefore, it was necessary to conduct a wick material evaluation program to select the wick material and establish its properties. The report on this test program is included in Appendix G.

Using the material performance established by the test program resulted in a wick separator volume of 2.62×10^{-3} m^3 (160 in^3) and a weight of 1.13 Kg (2.5 pounds).

A summary of the study conducted to establish the optimum means of driving each rotary device is included in Appendix H. The weight and volume figures included in Figures 4-5-15 and 4-5-16 reflect the use of the optimum prime mover for each rotary device. The weight and volume values shown in Figures 4-5-15 and 4-5-16 indicate that the wick systems are not competitive with the rotary systems; however, the wick systems were retained for system level evaluation in case a selected HRS and WMS combination was not compatible with a rotary device.



FIRST STAGE SLURPER/2ND STAGE WICK SEPARATOR
FIGURE 4-5-13

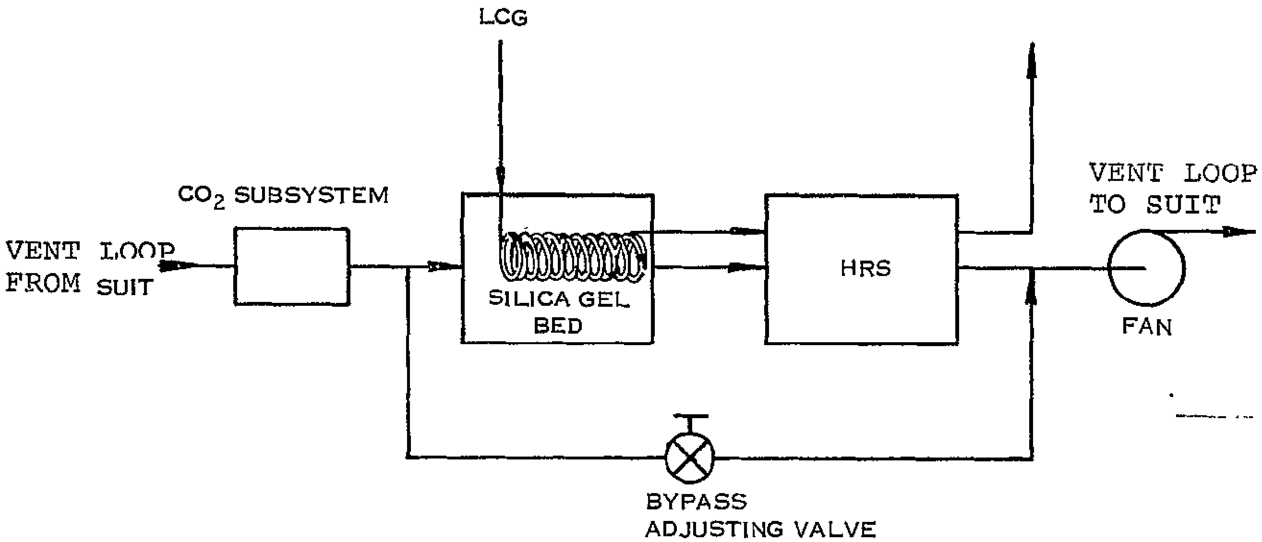


FIGURE 4-5-14
DESICCANT SUBSYSTEM

TABLE 4-5-1
HCS CONCEPTS EVALUATION - ABSOLUTE CRITERIA

Concept	Evaluation	
	Safety	Performance
Single Stage Fan Separator	Compliant	Compliant
Single Stage Motor Rotary Separator	Compliant	Compliant
Single Stage Wick Separator	Compliant	Compliant
First Stage Scupper Second Stage Fan Separator	Compliant	Compliant
First Stage Scupper Second Stage Motor Rotary Separator	Compliant	Compliant
First Stage Scupper Second Stage Wick	Compliant	Compliant
First Stage Slurper Second Stage Motor Rotary Separator	Compliant	Compliant
First Stage Slurper Second Stage Wick	Compliant	Compliant
Desiccant	Compliant	Compliant

TABLE 4-5-2

HCS CONCEPTS EVALUATION - RELATIVE CRITERIA

Concept	Development/ Availability	Gross Vehicle Launch Weight	EVLSS Volume	Results
	Evaluation			
Single Stage Fan Separator	Competitive	Not Competitive (See Figure 5-5-14)	Not Competitive (See Figure 5-5-15)	Reject
Single Stage Motor Rotary Separator	Competitive	Competitive	Competitive	Acceptable Candidate
Single Stage Wick Separator	Competitive	Competitive	Competitive	Acceptable Candidate
First Stage Scupper Second Stage Fan Separator	Competitive	Competitive	Competitive	Acceptable Candidate
First Stage Scupper Second Stage Motor Rotary Separator	Competitive	Competitive	Competitive	Acceptable Candidate
First Stage Scupper Second Stage Wick	Competitive	Competitive	Competitive	Acceptable Candidate
First Stage Slurper Second Stage Motor Rotary Separator	Competitive	Competitive	Competitive	Acceptable Candidate
First Stage Slurper Second Stage Wick	Competitive	Competitive	Competitive	Acceptable Candidate
Desiccant	Competitive	Not Competitive (See Figure 5-5-14)	Not Competitive (See Figure 5-5-15)	Reject

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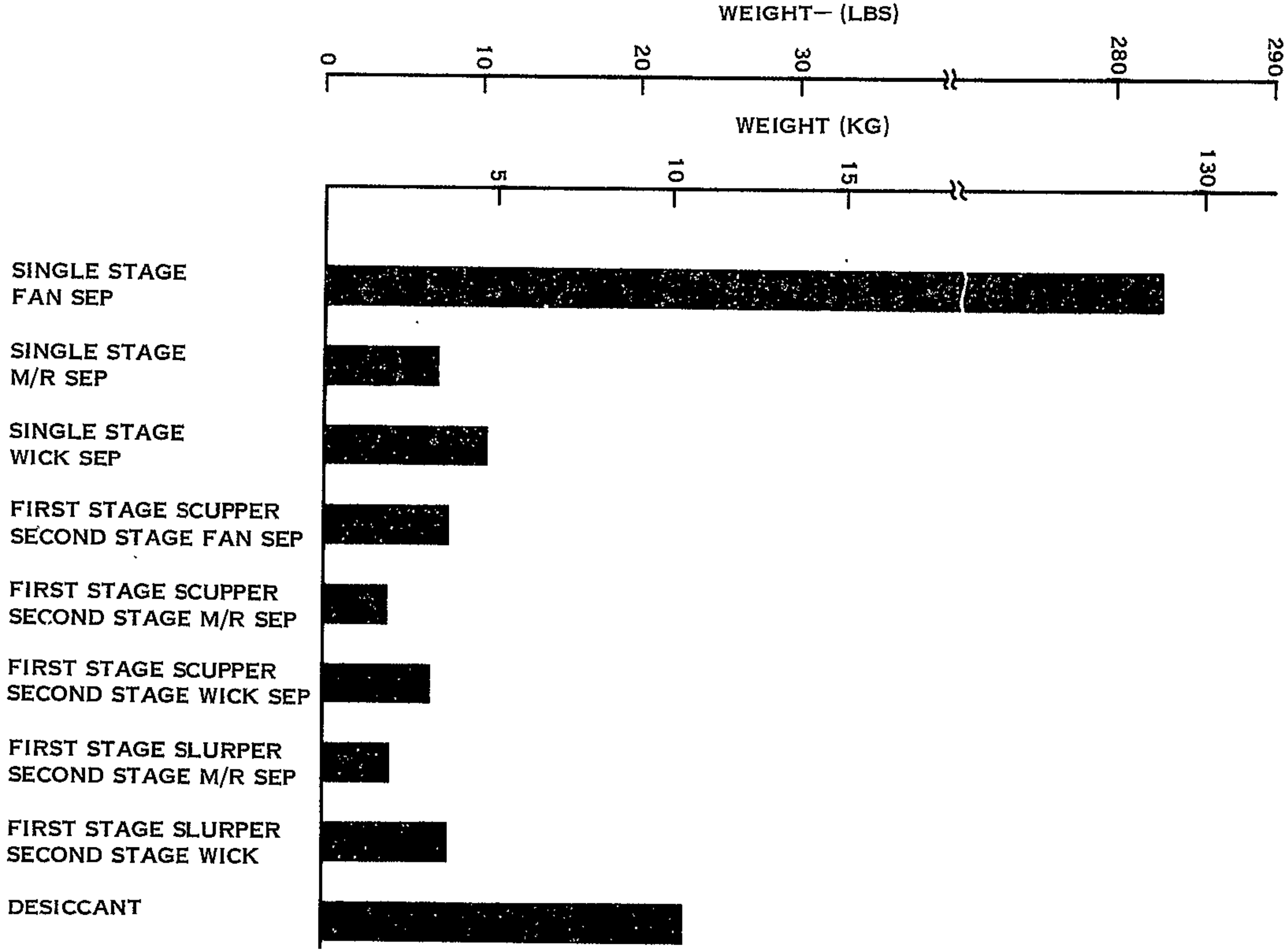


FIGURE 4-5-15 HCS WEIGHT

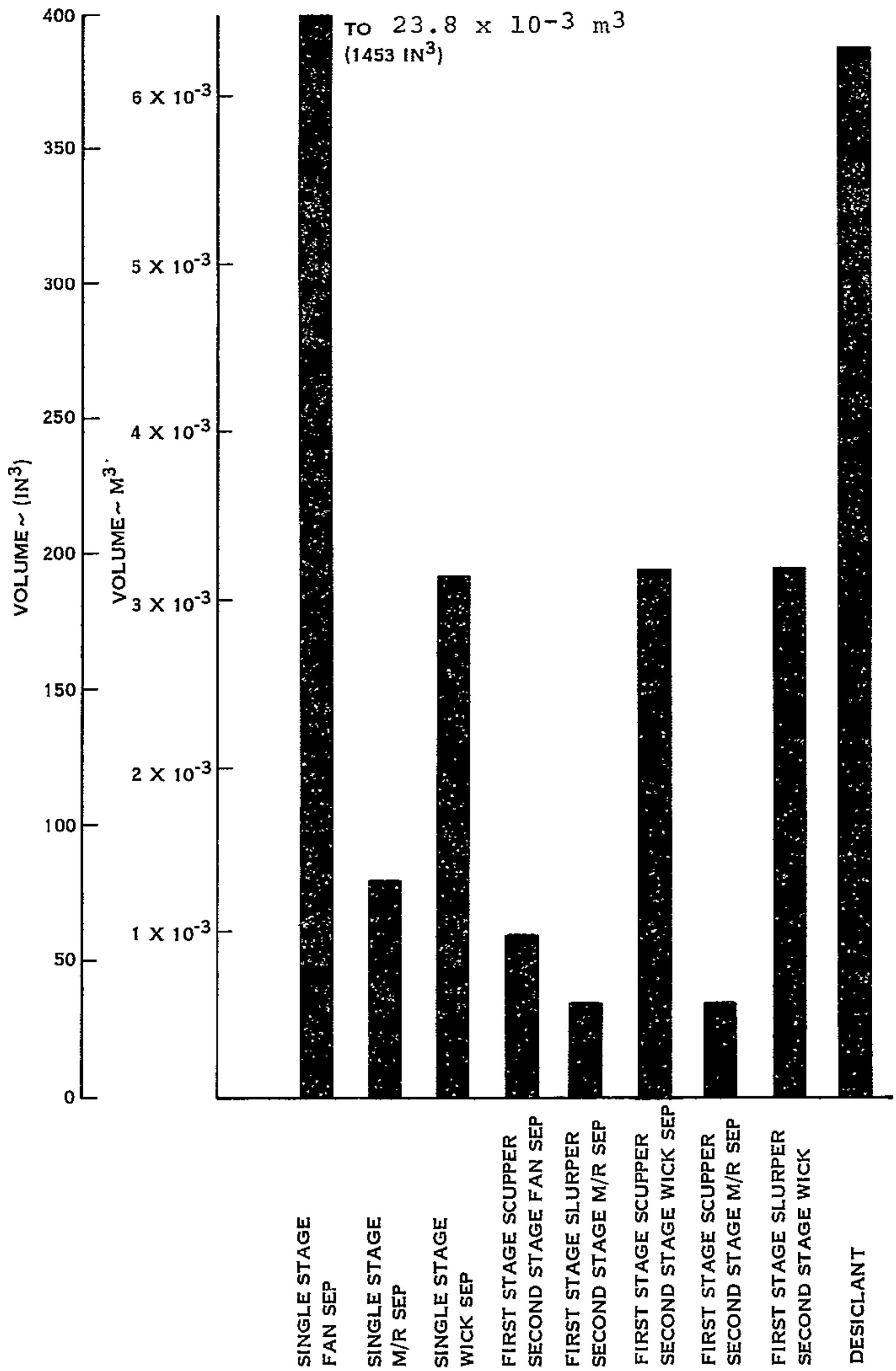


FIGURE 4-5-16 HCS VOLUME

4.6 LCG Pressure Control

4.6.1 Criteria Definition

The LCG pressure control candidates were evaluated first against two absolute criteria, and those found compliant were then rated against three relative criteria. The criteria are described below.

Absolute Criteria

Safety - Each concept was evaluated to determine if there were any hazards which could not be eliminated. Specifically, the concept could not present a toxicty hazard, it had to comply with the Apollo fire and explosion requirements, and a component failure could not result in gross vent loop leakage.

Performance - Each candidate had to be capable of meeting the following performance requirements.

- It must be capable of providing at least .15 Kg (.33 lb) of makeup water to the LCG circuit.
- It must be possible to prove zero "g" operation in a one "g" gravity field.

Relative Criteria

Development/Availability - The technology risk presented by each concept was assessed, and a determination was made about the ability to verify the feasibility of a concept within the limits of the TCS program.

EVLSS Weight - The relative hardware weight was assessed for each concept.

EVLSS Volume - The relative volume required to package each configuration was assessed.

4.6.2 LCG Pressure Control Candidate Definition and Evaluation

There were three LCG pressure control candidates considered.

Expendable Water for LCG Makeup (Figure 4-6-1) - This concept uses the expendable water in the WMS for pressure control and makeup water for the LCG loop. The check valve isolates the LCG to allow charging and test of the LCG loop independent of the expendable water.

4.6.2 (Continued)

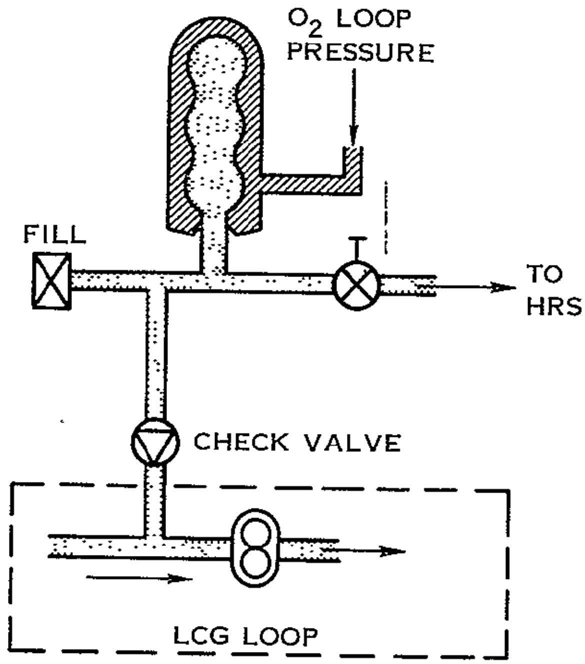


FIGURE 4-6-1
EXPENDABLE WATER

Accumulator (Pressure Loaded) (Figure 4-6-2) - This concept isolates the LCG makeup water from the expendable water supply by using an accumulator sized to provide all LCG loop makeup water required for any given Shuttle flight. Control of LCG loop pressure is achieved by loading a diaphragm in the accumulator with suit loop pressure.

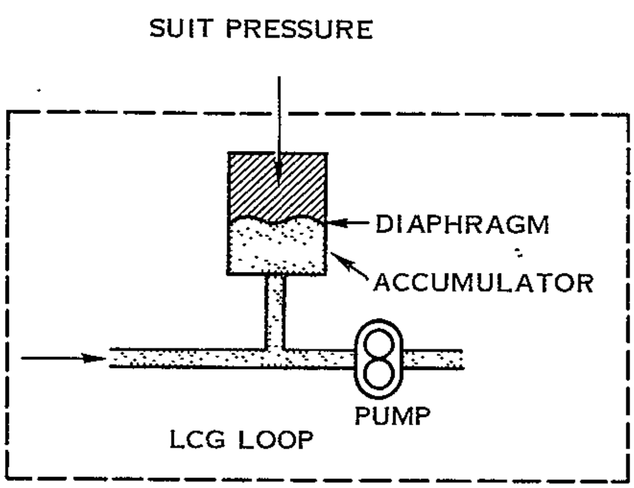


FIGURE 4-6-2
ACCUMULATOR

4.6.2 (Continued)

Accumulator (Spring Loaded) - This concept is the same as the previous one except that the accumulator is spring loaded rather than loaded by suit pressure.

Each of these concepts was previously used in flight applications so each was considered to be compliant with the absolute requirements; thus, the evaluation was made on the relative criteria as summarized in Table 5-6-1. The use of expendable water for LCG makeup was selected as a viable candidate as it was the smallest and lightest concept. The pressure loaded accumulator was retained as a candidate to be compatible with TCS concepts for which using expendable water for makeup was not feasible. The spring loaded accumulator had no advantages over the pressure loaded accumulator while having a slight weight and volume penalty and was dropped from further consideration.

4.7 LCG Temperature Control

4.7.1 Criteria Definition

The LCG temperature control candidates were evaluated first against two absolute criteria, and those found compliant were then rated against two relative criteria which were as follows.

Absolute Criteria

Safety - Each concept was evaluated to determine if there were any hazards which could not be eliminated. Specifically, the concept could not present a toxicty hazard, it had to comply with the Apollo fire and explosion requirements, and a component failure could not result in gross vent loop leakage.

Performance - Each candidate had to be capable of meeting the following performance requirements.

- The crewman must be able to manually select the amount of LCG cooling.
- It must be possible to prove zero "g" operation in a one "g" gravity field.
- Control of the LCG temperature must not result in a vent loop temperature above 10^{o}C (50^{o}F).

Relative Criteria

Development/Availability - The technology risk presented by each concept was assessed, and a determination was made about the ability to verify the feasibility of a concept within the limits of the TCS program.

EVLSS Volume - The relative volume required to package each configuration was assessed.

TABLE 4-6-1
LCG PRESSURE CONTROL CONCEPT PRELIMINARY SCREENING

Concept	Development/ Availability	Evaluation EVLSS Weight (Ref. Figure 5-6-3)	EVLSS Volume (Ref. Figure 5-6-3)	
Expendable Water For LCG Makeup	Competitive	Competitive	Competitive	Selected
Pressure Loaded Accumulator	Competitive	Competitive*	Competitive*	Selected
Spring Loaded Accumulator	Competitive	Not Competitive	Not Competitive	Not Selected

*Concept larger and heavier than using expendable water but was selected for use in systems which cannot use expendable water.

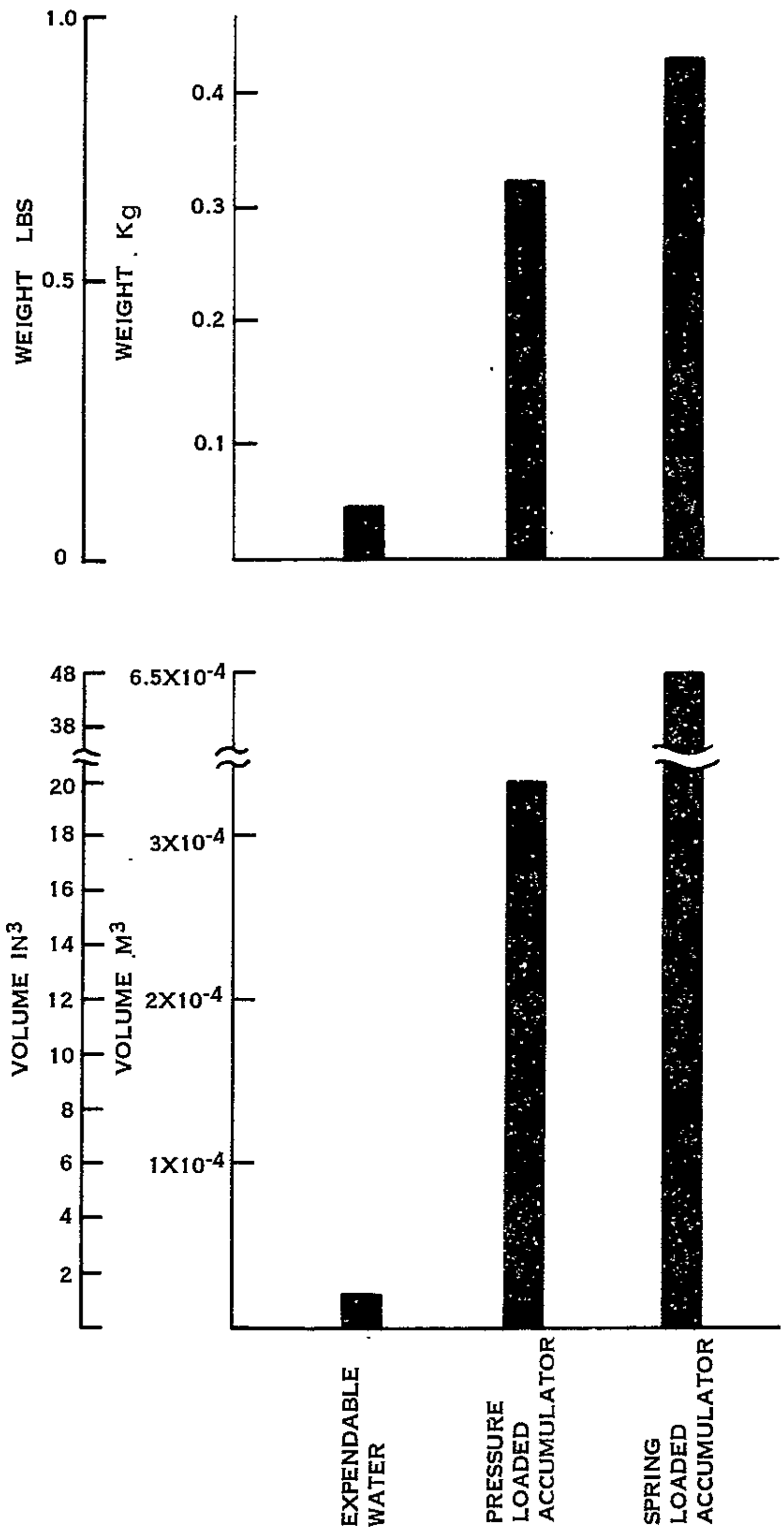


FIGURE 4-6-3 WEIGHT AND VOLUME VS LCG PRESSURE CONTROL CONCEPT

4.7.2 LCG Temperature Control Candidate Definition and Evaluation

Five LCG temperature control candidates were considered.

LCG Inlet Temperature Control (Figure 4-7-1) - This is the same as the concept used in the Apollo PLSS. The crewman may select a wide variety of LCG inlet temperatures for maximum comfort. Warm water from the LCG is diverted around the HRS heat exchanger by the manual diverter valve. The proper LCG inlet temperature for thermal comfort is established by varying the amount of flow bypassed around the heat exchanger.

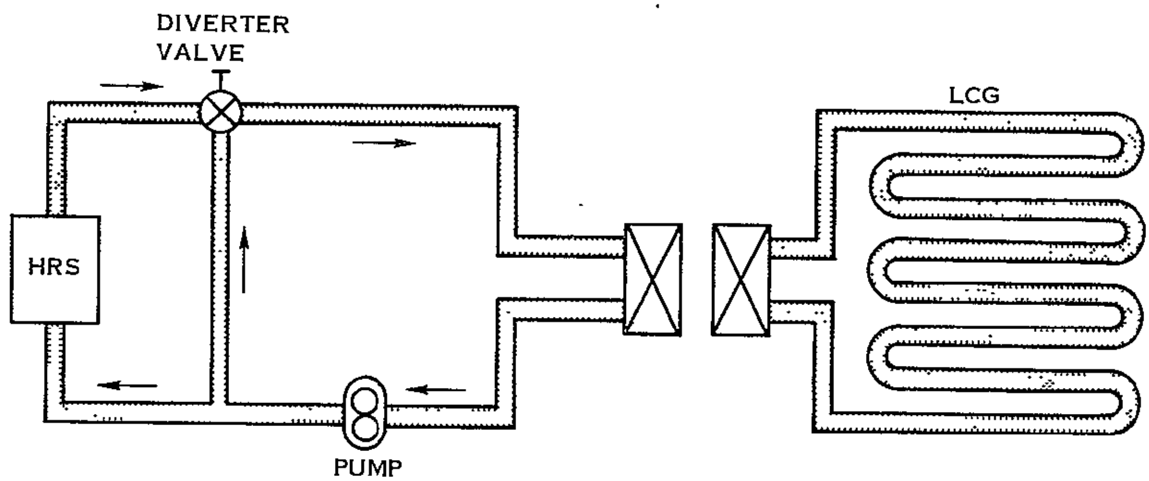


FIGURE 4-7-1
LCG INLET TEMPERATURE CONTROL

LCG Inlet Flow Control (Figure 4-7-2) - This concept is similar to the concept of the Skylab Astronaut Life Support Assembly (ALSA). The diverter valve diverts the chilled water from the HRS heat exchanger around the LCG. For minimum cooling needs, the crewman increases LCG bypass flow. If the inlet water temperature is nearly constant, the cooling capacity is linearly proportional to the flow through the LCG.

4.7.2 (Continued)

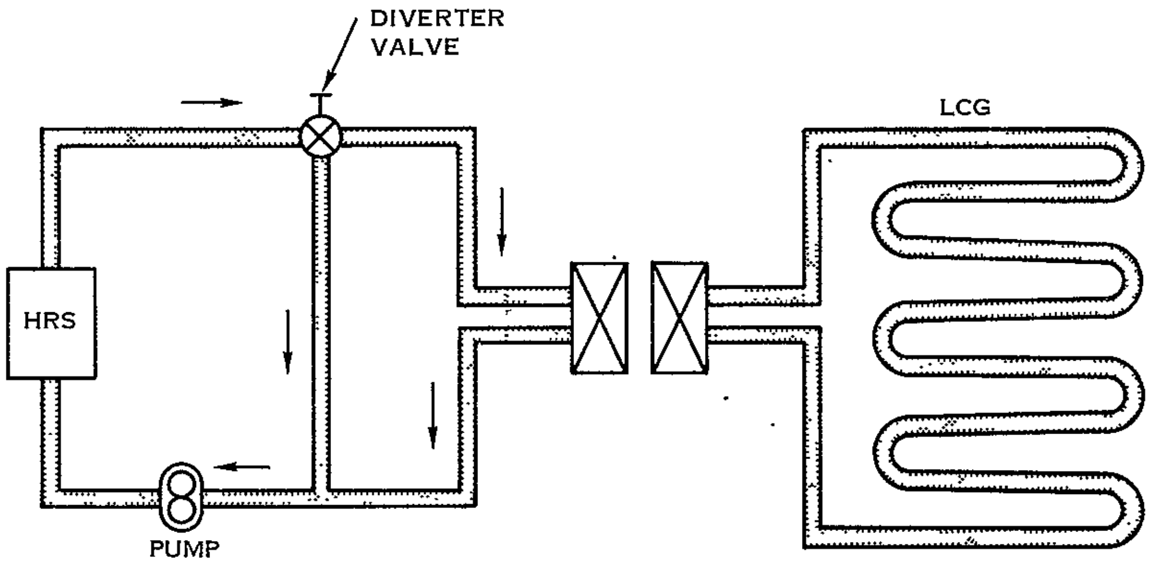


FIGURE 4-7-2
LCG INLET FLOW CONTROL

<u>LCG Loop Flow Control (Figure 4-7-3)</u> - Control of LCG cooling can be accomplished by bypassing the flow around the cooling loop pump. With this concept, flow is reduced in the heat exchanger as well as in the LCG.

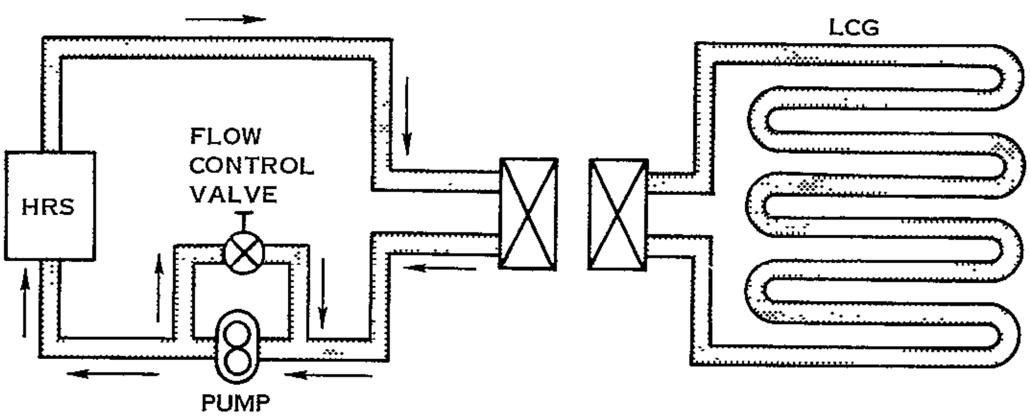


FIGURE 4-7-3
LCG LOOP FLOW CONTROL

4.7.2 (Continued)

LCG Temperature Control (Figure 4-7-4) - If an electronically controlled HRS is used, the concept shown in Figure 4-7-4 is a method of providing LCG temperature control.

The crewman may manually set the HRS downstream control temperature that makes him comfortable.

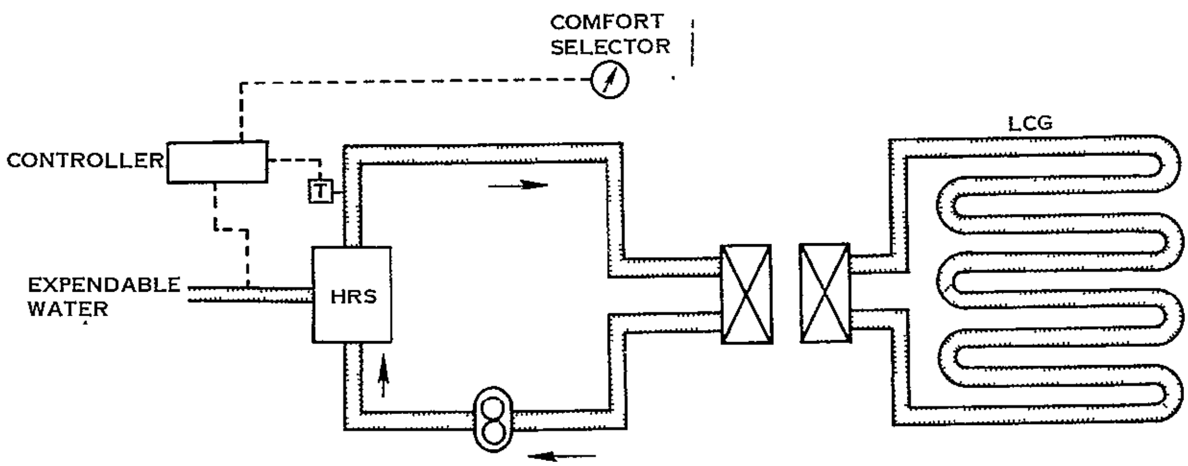


FIGURE 4-7-4
LCG TEMPERATURE FLOW CONTROL

Feed Water Flow Control (Figure 4-7-5) - If a sublimator should be selected for the HRS, control of the expendable water flow may be implemented as a means of LCG cooling control. A representative concept is shown in Figure 4-7-5 where a selector valve controls the expendable water flow to each of the sections of a multiple selection sublimator. This concept was used in the Litton Portable Environmental Control System.

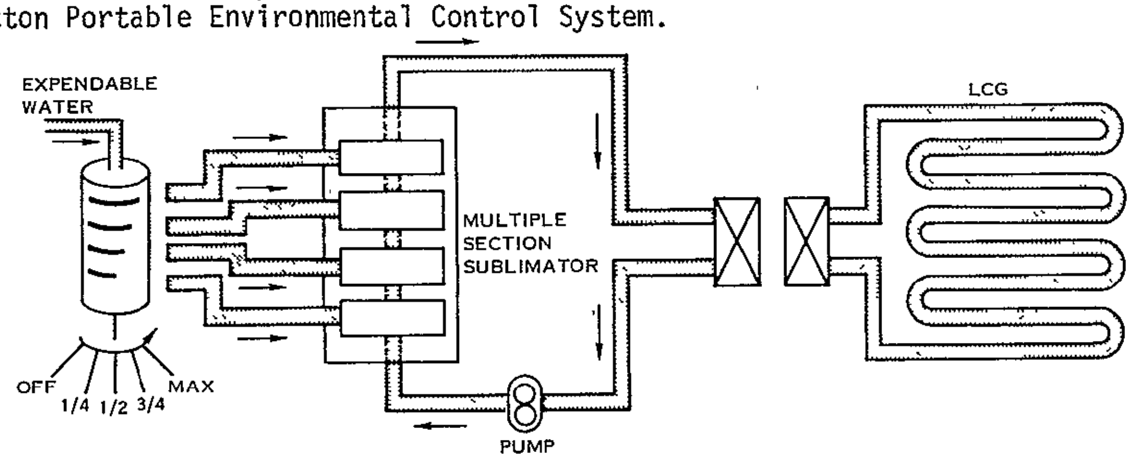


FIGURE 4-7-5
FEED WATER FLOW CONTROL

4.7.2 (Continued)

Each of the concepts was compliant with the safety requirements; however, from a performance standpoint, the LCG loop flow control, LCG temperature control and feed water flow were unacceptable since in each case the LCG portion of the HRS, which is the sink for the vent loop, could exceed °C (50°F). To resolve this deficiency, a separate HRS would be required for the vent loop, imposing significant weight volume and cost penalties. Thus, these three concepts were not considered further. A detailed study was conducted to determine which of the two remaining systems was more suited for use in the TCS. This study is included in Appendix I and identified LCG inlet flow control as the optimum means of providing LCG thermal control, primarily due to weight advantages.

4.8 Thermal Control System Evaluation

The two competitive heat rejection subsystems, the three remaining water management subsystems and the seven humidity control subsystems were combined to form the candidate thermal control system. Only those systems which could meet the performance requirements were defined. Appendix J contains a schematic, a functional description and a weight, volume and operational procedure summary for each of the candidate concepts.

4.8.1 Evaluation Criteria

Since all the systems defined met the performance criteria, the evaluation was conducted on the basis of the following relative criteria.

Vehicle Launch Weight - Vehicle launch weight is comprised of the summation of the weight of two EVLSS's launched dry, the vehicle power penalty based on 1.92 lbs/kwh and six dual EVA's.

EVLSS Volume - EVLSS volume is the summation of the estimated component and packaging hardware volumes.

Program Cost - Program cost consists of a relative assessment of the ground maintenance cost for each flight, the design and development cost, the cost of 18 sets of TCS hardware, and the vehicle weight penalty based on a cost of $35,000/lb.

Operability - Operability consists of an assessment of the ease of start up, shutdown, check out, recharge and ground maintenance of the TCS.

Complexity - The concepts were ranked by a subjective assessment of component functional and physical intricacy and the number and interrelationship of components in the system arrangement.

Reliability - This consisted of an assessment of the critical failure modes affecting crew safety.

4.8.2 TCS Concept Identification

Table 4-8-1 identifies the 16 combinations of the competitive water management subsystems, heat rejection subsystems, and humidity control subsystems. The rotary separator concepts are not compatible with the high pressure storage concept because the pressure level imposes severe power penalties on the rotary devices. The bubble expansion tank and the bladder tank storage with pressure regulator concepts are not compatible with the flash evaporator because a minimum of 30 psi is required for operation.

4.8.3 TCS Evaluation and Selection

A relative rating factor for each evaluation criteria was established for each concept. When these ratings were summarized and totaled (Table 4-8-2), it was determined that two concepts had the best ratings in each category; however, one of the two systems was lighter and smaller than the other. This concept consisted of a sublimator heat rejection subsystem, a bubble expansion tank water management subsystem, and a slurper/rotary separator humidity control subsystem (Figure 4-8-1). Thus, this was the selected concept.

Figures 4-8-2 and 4-8-3 respectively show the ratings for vehicle launch weight and EVLSS volume. The relative numbers shown were established by using the weight and volume numbers defined in Appendix J. In establishing the rating, any concept within 10% of the least weight or volume concept was given a rating of 1. Those concepts between 10 and 20% were rated 2 and so on. The relative cost shown in Figure 4-8-4 was established based on an assessment of the nonrecurring cost to design and develop a concept, the cost to fabricate 18 units, a moderate allowance for replacement of limited life items, and the vehicle weight penalty cost. The rating was for any system within 10% of the least cost system was 1, for systems within 20%, the rating was 2, and for those within 30%, the rating was 3. It should be noted that almost all of the systems were within 20% of the least expensive, so cost alone could not be considered a driving factor.

Operability was an assessment of the ease of start up, shutdown, check out, recharge and ground maintenance of the TCS. There was no significant difference in the ground maintenance identified, all concepts required between 9 and 11 steps for recharge and start up and shutdown procedures were approximately the same for all concepts. The rating was established on the number of recharge steps. Because of the small differences between systems, it was necessary to prevent operability from being a driving factor in the concept selection. Thus, ratings of .1, .2, and .3 were used as summarized in Figure 4-8-5.

The concepts had between 15 and 19 components of which many were common or similar. For example, all systems had a water reservoir, relief valves, and shutoff valves, and the bubble expansion tank was similar to the accumulator while the flash evaporator heat exchanger, plus the separate two fluid heat exchanger was essentially equivalent to the sublimator. Thus, the complexity rating was established by considering the non-common components which were more complex than a simple shutoff valve or relief valve. For this evaluation, motor electronics, controller electronics and oxygen regulators were given a

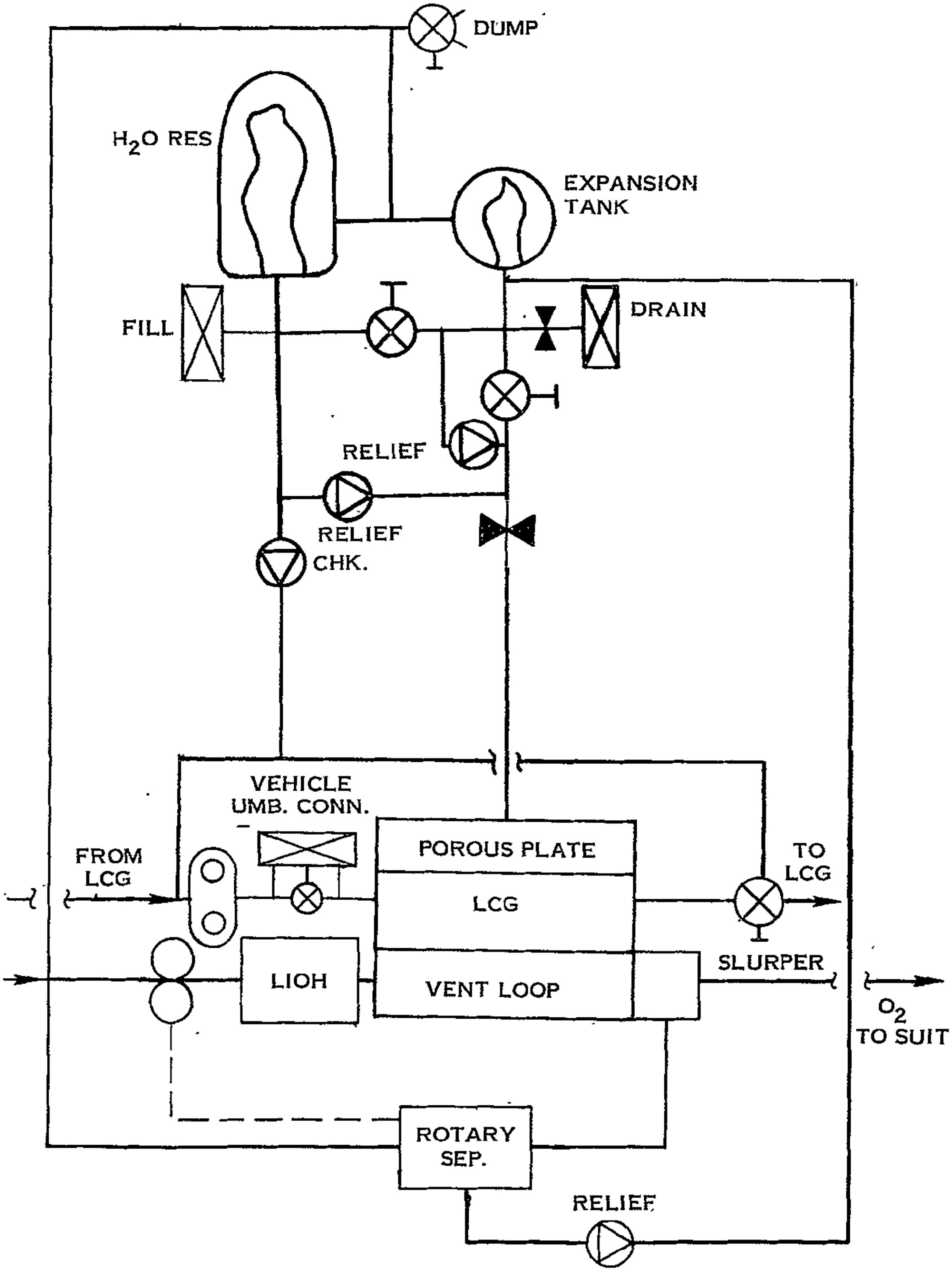
WATER MANAGEMENT SUBSYSTEM	HUMIDITY CONTROL SUBSYSTEM							HEAT REJECTION SUBSYSTEM
	SINGLE STAGE MOTOR/ ROTARY SEPARATOR	SINGLE STAGE ELBOW WICK SEPARATOR	1ST STAGE SCUPPER/ 2ND FAN SEPARATOR	1ST STAGE SCUPPER/ 2ND STAGE MOTOR/ ROTARY SEPARATOR	1ST STAGE SCUPPER/ 2ND STAGE WICK STORAGE	1ST STAGE SLURPER/ 2ND STAGE MOTOR/ ROTARY SEPARATOR	1ST STAGE SLURPER/ 2ND STAGE WICK STORAGE	
BUBBLE EXPANSION TANK	1	2	3	4	5	6	7	SUBLIMATOR
HIGH PRESSURE STORAGE	NO	8	NO	NO	9	NO	10	
BLADDER TANK STORAGE WITH PRESSURE REG	NO	11	NO	NO	12	NO	13	
BUBBLE EXPANSION TANK	NO	NO	NO	NO	NO	NO	NO	FLASH EVAPORATOR
HIGH PRESSURE STORAGE	NO	14	NO	NO	15	NO	16	
BLADDER TANK STORAGE WITH PRESSURE REG	NO	NO	NO	NO	NO	NO	NO	

TABLE 4-8-1
TCS SYSTEMS

TABLE 4-8-2

TCS EVALUATION SUMMARY

Concept No.	Weight	Volume	Cost	Rating Operability	Complexity	Reliability	Total
1	2	1	2	.1	2	1	8.1
2	3	3	2	.3	1	2	11.3
3	2	1	3	.1	2	1	9.1
4	1	1	1	.1	1	1	5.1
5	3	3	2	.3	1	2	11.3
6	1	1	1	.1	1	1	5.1
7	2	3	1	.3	1	2	9.1
8	3	2	2	.2	3	3	13.2
9	3	2	2	.2	3	3	13.2
10	3	2	2	.2	3	3	13.2
11	3	2	1	.2	2	2	10.2
12	3	2	1	.2	2	2	10.2
13	2	2	1	.2	2	2	9.2
14	3	4	2	.2	4	2	15.2
15	3	4	2	.2	4	2	15.2
16	3	4	2	.2	4	2	15.2



CONCEPT 6 - SUBLIMATOR, BUBBLE EXPANSION TANK, 1ST STAGE SLURPER 2ND STAGE ROTARY SEPARATOR

FIGURE 4-8-1

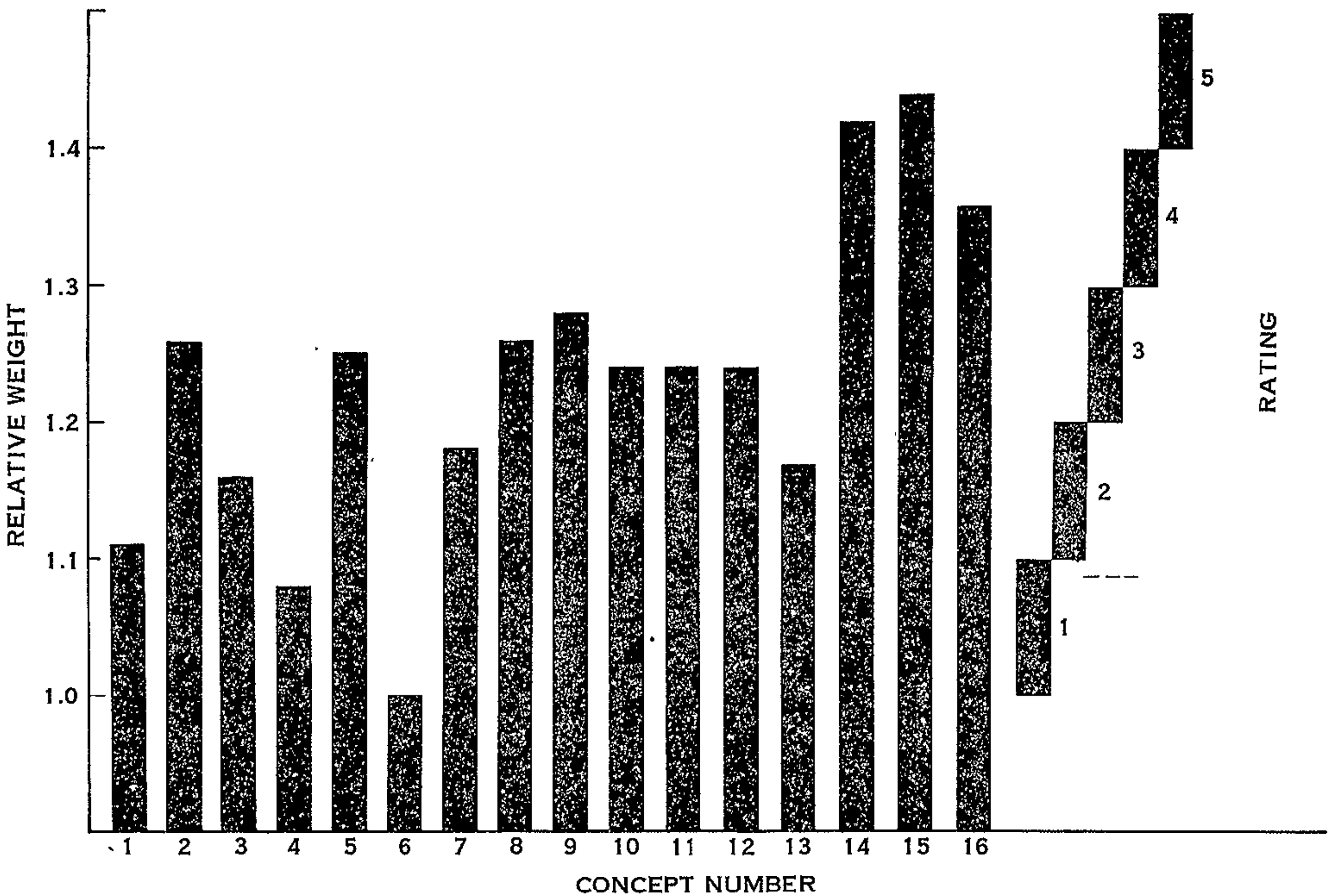


FIGURE 4-8-2 VEHICLE LAUNCH WEIGHT RATING

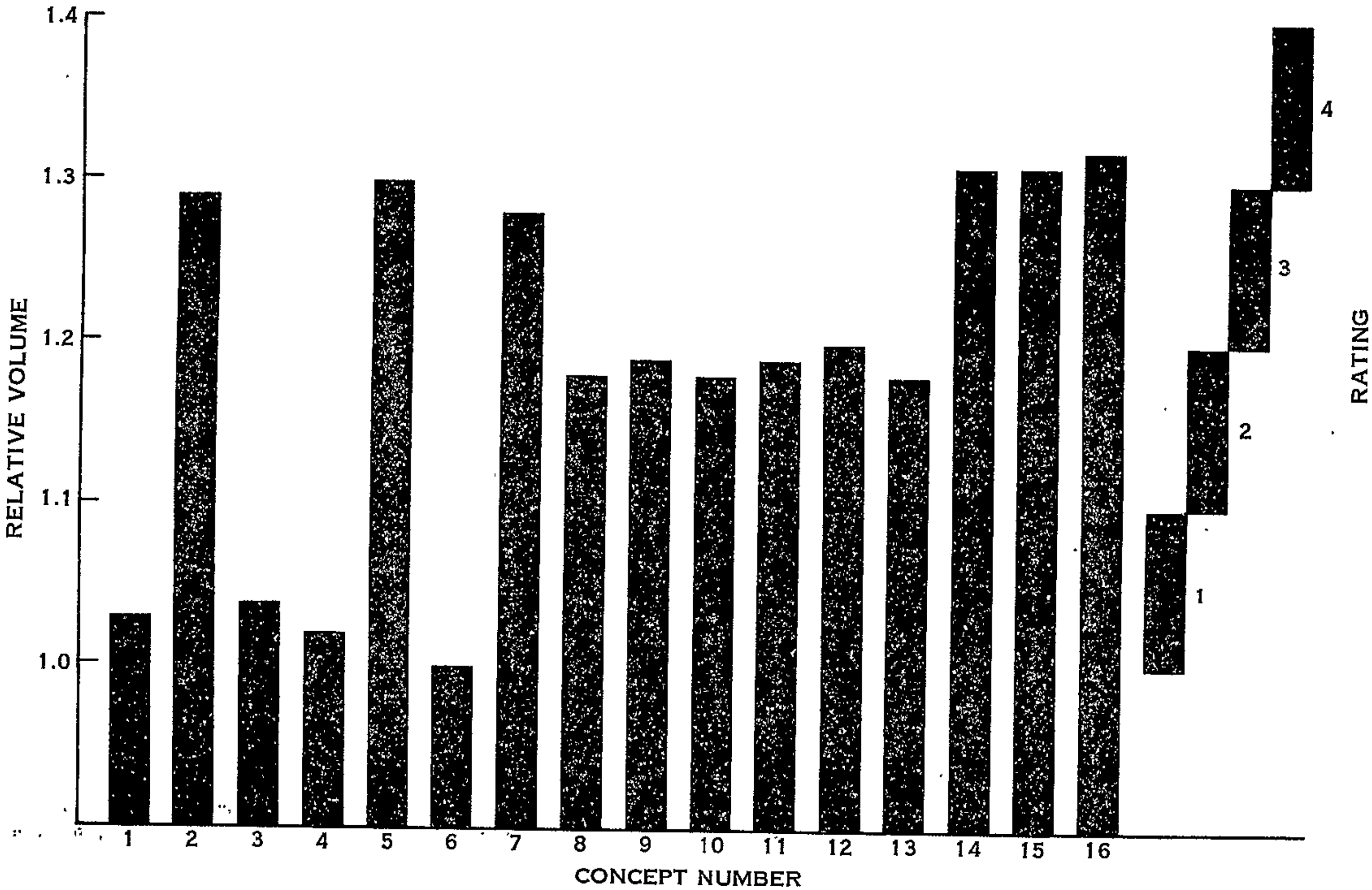


FIGURE 4-8-3 EVLSS VOLUME RATING

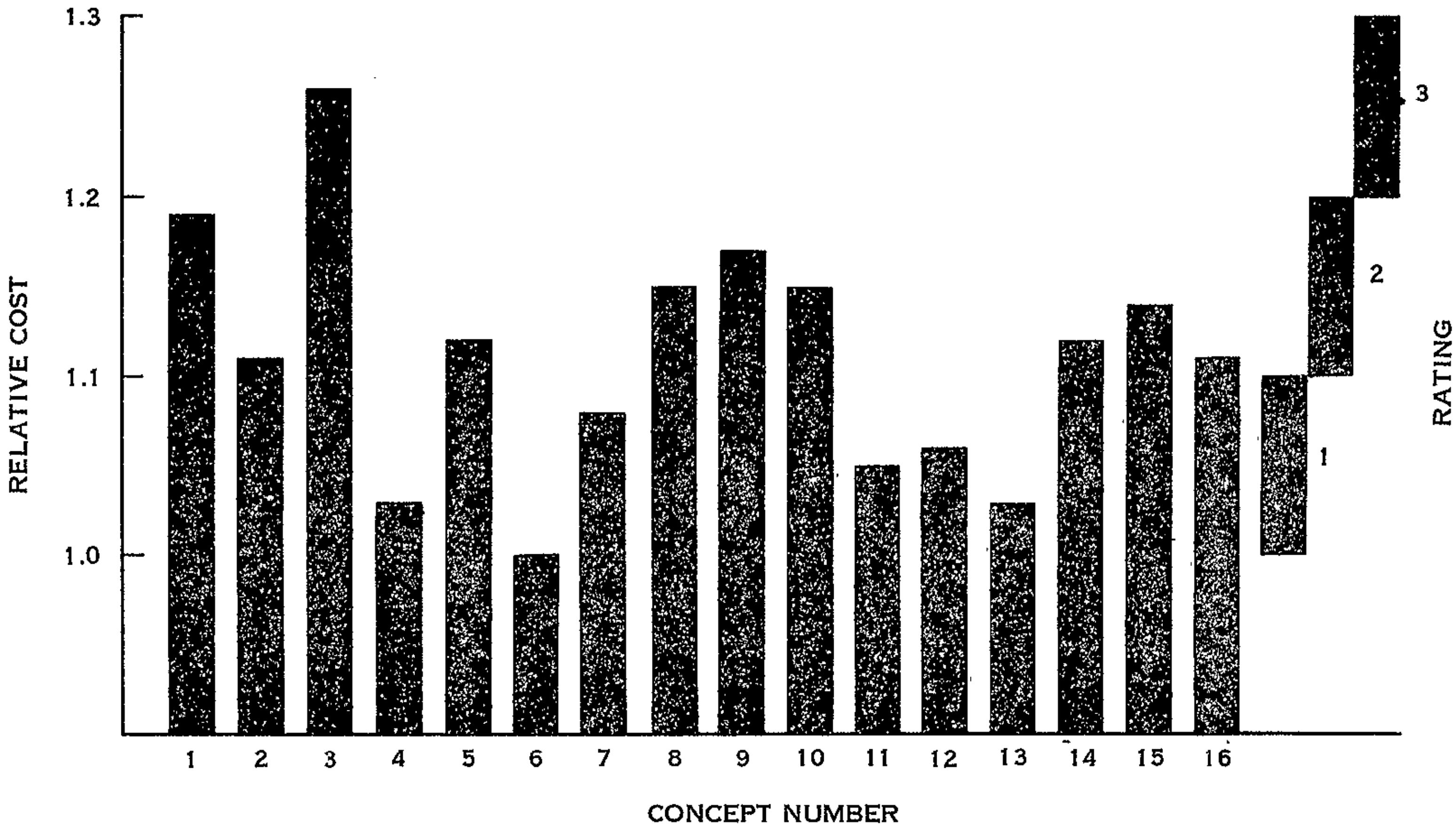


FIGURE 4-8-4 RELATIVE COST RATING

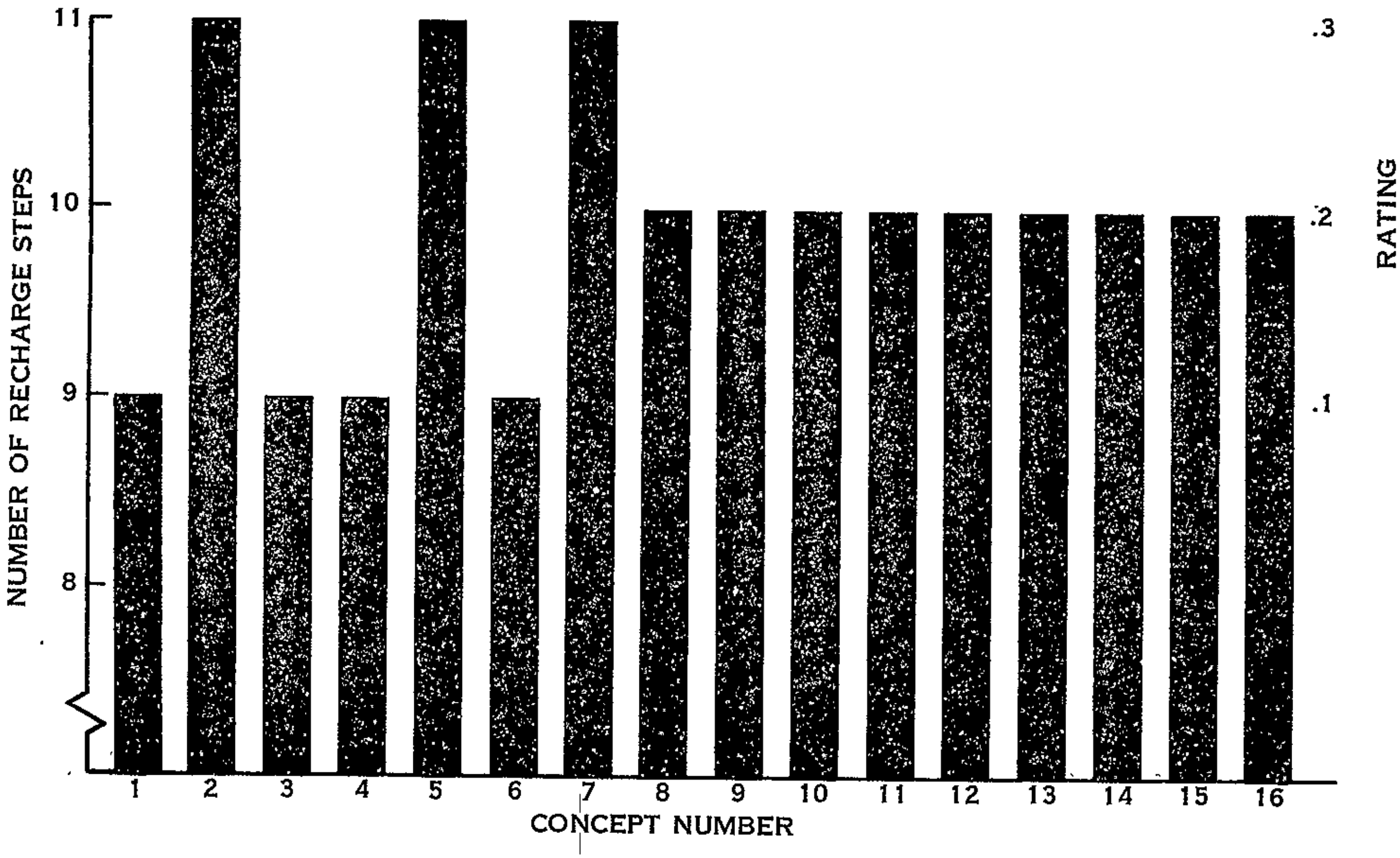


FIGURE 4-8-5 OPERABILITY RATING SUMMARY

4.8.3 (Continued)

rating of 2, while the mechanical portion of a motor, a wick separator, a rotary separator, a flash evaporator nozzle solenoid valve and a 3 way valve were given a rating of 1. Table 4-8-3 lists the concepts, the components considered and the total component rating. The component ratings were converted to system ratings as follows.

Component Rating	System Rating
1-2	1
3-4	2
5-6	3
7-8	4

The reliability evaluation consisted of an assessment of the critical failure modes affecting crew safety. Concepts 1, 3, 4 and 6 were rated first because they have no critical failure modes. Concepts 2, 5, 7 and 11 through 16 were rated second because the potential exists for a primary O_2 ventilation loop leak to vacuum through the elbow wick separator bladder or valve even though an orifice limits the leakage rate. Concepts 8, 9 and 10 were given the lowest reliability rating because the potential exists, although slight, for over pressurizing the WMS, the HRS and the primary O_2 ventilation loop from the high pressure regulators failing open.

Concept 6 (Figure 4-8-1) was selected as the best concept because it had the best rating in each category.

4.8.4 Systems Requiring Only One Half Hour Umbilical Operation and Gas Free Water Systems

Umbilical operation for up to 4.5 hours and a vehicle potable water supply saturated with nitrogen are conditions that affect the weight, volume, operability and complexity of the TCS. Systems with saturated water requiring only one half hour of umbilical operation and systems utilizing gas free water with both a half hour and 4.5 hour umbilical requirement were studied and evaluated. This was done to permit the assessment of other potentially competitive concept and mission options and their interrelationship.

Gas free water from the vehicle fuel cell can be obtained in two ways. If the potable water tanks utilize a rubber bladder, the incorporation of a back flow check valve in the fuel cell to potable tank line downstream of the EVLSS charging line permits the acquisition of gas free water. Gas free water may also be obtained by utilizing a metal bellows in the potable water tanks rather than rubber bladders eliminating gas permeation.

TABLE 4-8-3
COMPLEXITY EVALUATION

Concept	Components Considered	Component Rating	System Rating
1	Motor, Electronics, Rotary Separator	4	2
2	Wick, 3 Way Valve	2	1
3	Motor, Electronics, Rotary Separator	4	2
4	Rotary Separator	1	1
5	Wick, 3 Way Valve	2	1
6	Rotary Separator	1	1
7	Wick, 3 Way Valve	2	1
8	H_2O Reg, O_2 Reg, Wick, 3 Way Valve	5	3
9	H_2O Reg, O_2 Reg, Wick, 3 Way Valve	5	3
10	H_2O Reg, O_2 Reg, Wick, 3 Way Valve	5	3
11	H_2O Reg, Wick, 3 Way Valve	3	2
12	H_2O Reg, Wick, 3 Way Valve	3	2
13	H_2O Reg, Wick, 3 Way Valve	3	2
14	O_2 Reg, Controller, Wick, 3 Way Valve, Nozzle/Solenoid	7	4
15	O_2 Reg, Controller, Wick, 3 Way Valve, Nozzle/Solenoid	7	4
16	O_2 Reg, Controller, Wick, 3 Way Valve, Nozzle/Solenoid	7	4

4.8.4 (Continued)

All of the previously mentioned thermal control systems remain unchanged when the umbilical requirement is reduced to one half hour. However, it does permit the introduction of a thermal control system utilizing an elbow wick separator that has the capacity to store up to half hour of condensate; and then, when the HRS is started up, transferring it and any additional condensate to the back side of the bladder in the water reservoir. This is depicted by concept 17 (Figure 4-8-6). A functional description along with the weight and volume summaries for this concept are included in Appendix J. Again, concept 6 was found to be the best concept.

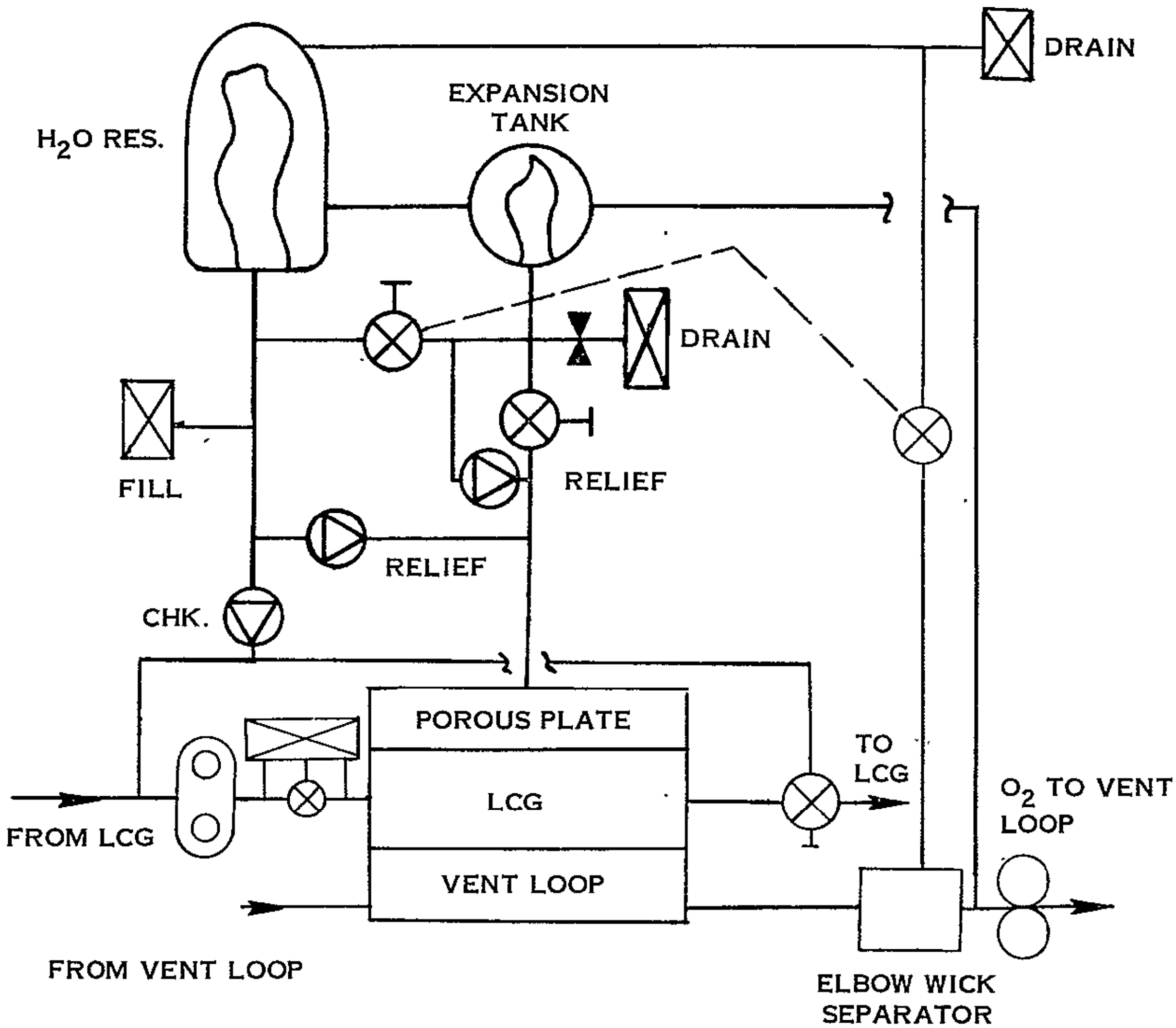
Table 4-8-4 identifies that 19 viable combinations of the competitive water management subsystems, heat rejections subsystems and humidity control subsystems that are compatible with gas free water. The bladder tank reservoir for the sublimator and the bladder tank reservoir with a pump for the flash evaporator, the three fluid sublimator and the two two-fluid flash evaporator, the single stage motor/rotary separator, the single stage elbow wick separator, a single stage elbow wick separator with reservoir storage for 30 minute umbilical operation, a first stage scupper in combination with either a second stage fan separator, motor/rotary separator or elbow wick separator and a first stage slurper in combination with either a second stage motor rotary separator or elbow wick separator are the competitive subsystems. The rotary separators are not compatible with high pressure storage subsystems because the pressure level imposes severe power penalties on rotary devices. Concept 24 (Figure 4-8-7)was found to be the best concept for gas gree water and umbilical operation of 4.5 hour operation and gas free water and 30 minutes operation.

4.9 Heat Rejection Subsystem Feasibility Test and Design Details

In support of the HRS design, a feasibility test program was conducted to obtain data for various porous plate materials. Figure 5-9-1 shows the test fixture utilized for these tests. With this device, the porous plate/heat exchanger interface was simulated while the thermal load was controlled by the two heaters in contact with the housing.

Testing consisted of: 1) steady state calibration during which the average housing temperature was obtained at various heat loads, and 2) hot start up performance during which the feed water flow was initiated after the entire test unit was stabilized at 38°C (100°F) to 40.4°C (105°F). The hot start test simulated the worst case heat soak in the vehicle and assumed no umbilical cooling of the system or crewman prior to start up.

Various plate materials were tested including sintered stainless steel, sintered teflon, sintered nickel and calendered multi-layer stainless steel screens. The calendered multi-layer stainless steel screen plate was found to be the most suitable for the HRS application. Figure 5-9-2 is a plot of average housing temperature versus heat load for the calendered stainless steel screen plate.



CONCEPT 17 - SUBLIMATOR, BUBBLE EXPANSION TANK, SINGLE STAGE ELBOW WICK SEPARATOR PLUS RESERVOIR STORAGE

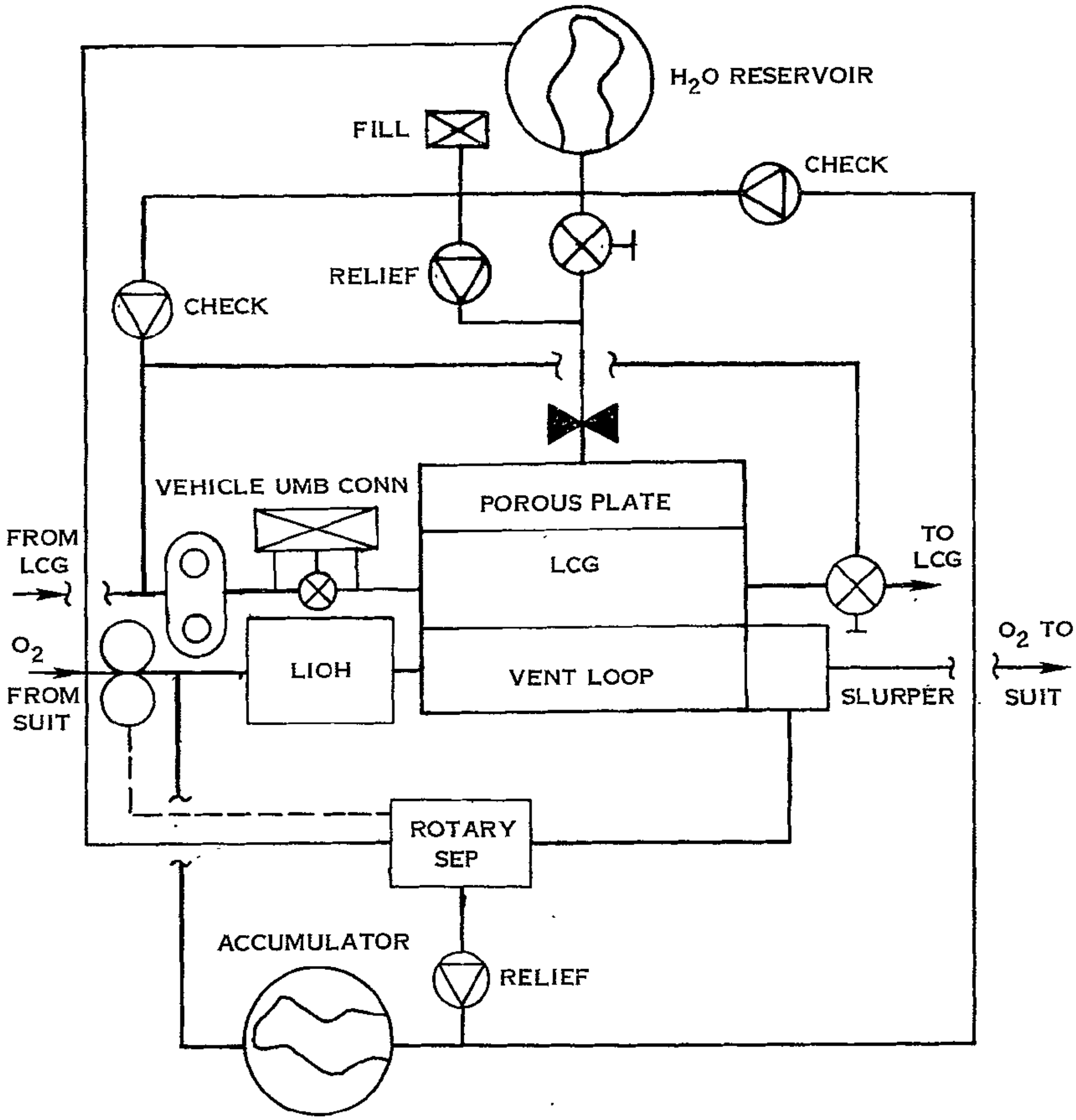
FIGURE 4-8-6

CANDIDATE SYSTEM MATRIX
(GAS FREE WATER)

WATER MANAGEMENT SUBSYSTEM	HUMIDITY CONTROL SUBSYSTEM								HEAT REJECTION SUBSYSTEM
	SINGLE STAGE MOTOR ROTARY SEPARATOR	SINGLE STAGE ELBOW WICK SEPARATOR	ELBOW WICK SEPARATOR WITH RESERVOIR STORAGE	1ST STAGE SCUPPER/ 2ND STAGE FAN SEPARATOR	1ST STAGE SCUPPER/ 2ND STAGE MOTOR/ROTARY SEPARATOR	1ST STAGE SCUPPER/ 2ND STAGE WICK	1ST STAGE SLURPER/ 2ND STAGE MOTOR/ROTARY SEPARATOR	1ST STAGE SLURPER/ 2ND STAGE WICK	
SIMPLE BLADDER TANK RESERVIOR	18	19	* 20	21	22	23	24	25	SUBLIMATOR
SIMPLE BLADDER TANK RESERVIOR (WITH PUMP)	26	27	* 28	29	30	31	32	33	FLASH EVAPORATOR
HIGH PRESSURE STORAGE	NO	14	NO	NO	NO	15	NO	16	

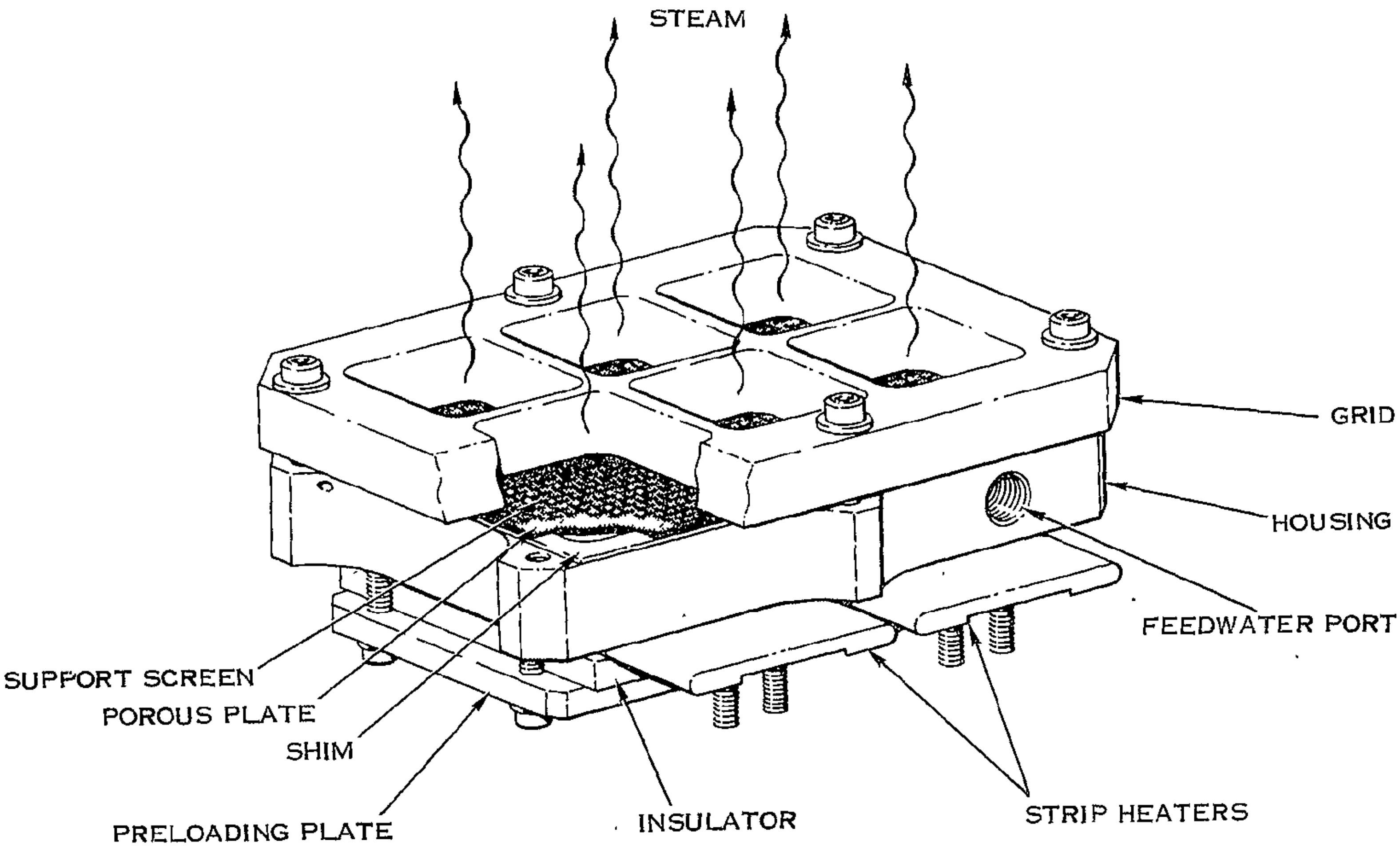
* CONCEPT ONLY APPLICABLE TO 1/2 HOUR UMBILICAL OPERATION

TABLE 4-8-4



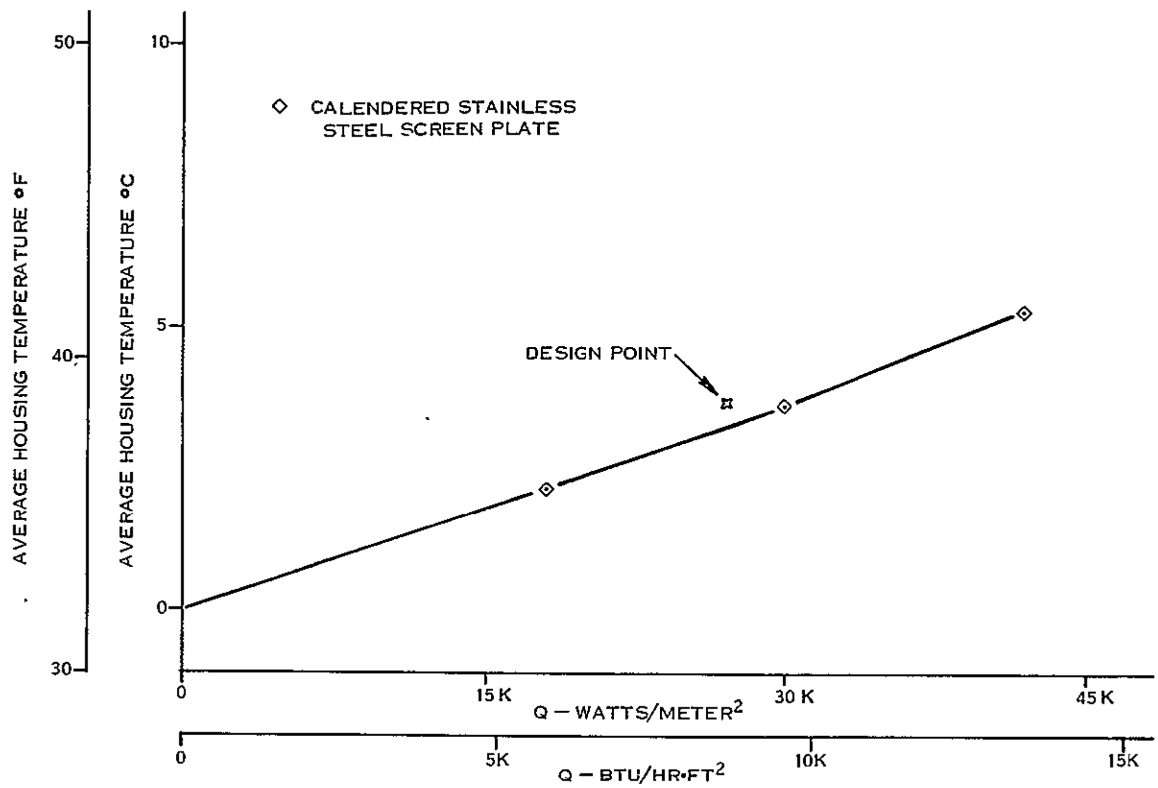
CONCEPT 24 - SUBLIMATOR, SIMPLE BLADDER TANK, 1ST STAGE SLURPER 2ND STAGE ROTARY SEPARATOR

FIGURE 4-8-7



FEASIBILITY WATER SUBLIMATOR

FIGURE 4-9-1



AVERAGE TEMPERATURE VS HEAT LOAD

FIGURE 4-9-2

4.9 (Continued)

The Figure also shows the design point utilized in sizing the TCS sublimator (reference SVSK 87320). The unit was sized to reject a maximum load of 909 watts (3,100 Btu/hr) and a minimum load of 70 watts (240 Btu/hr) which were established as shown in Table 4-9-1.

TABLE 4-9-1
SUBLIMATOR HEAT LOAD

Constituent	Minimum Load Watts	Minimum Load Btu/Hr	Maximum Load Watts	Maximum Load Btu/Hr
Metabolic Load	117	400	587	+2,000
LiOH Load	0	+0	162	+560
Heat Leak	-117	-400	90	+300
Equipment Load	70	240	70	240
Total	70	240	909	~3,100

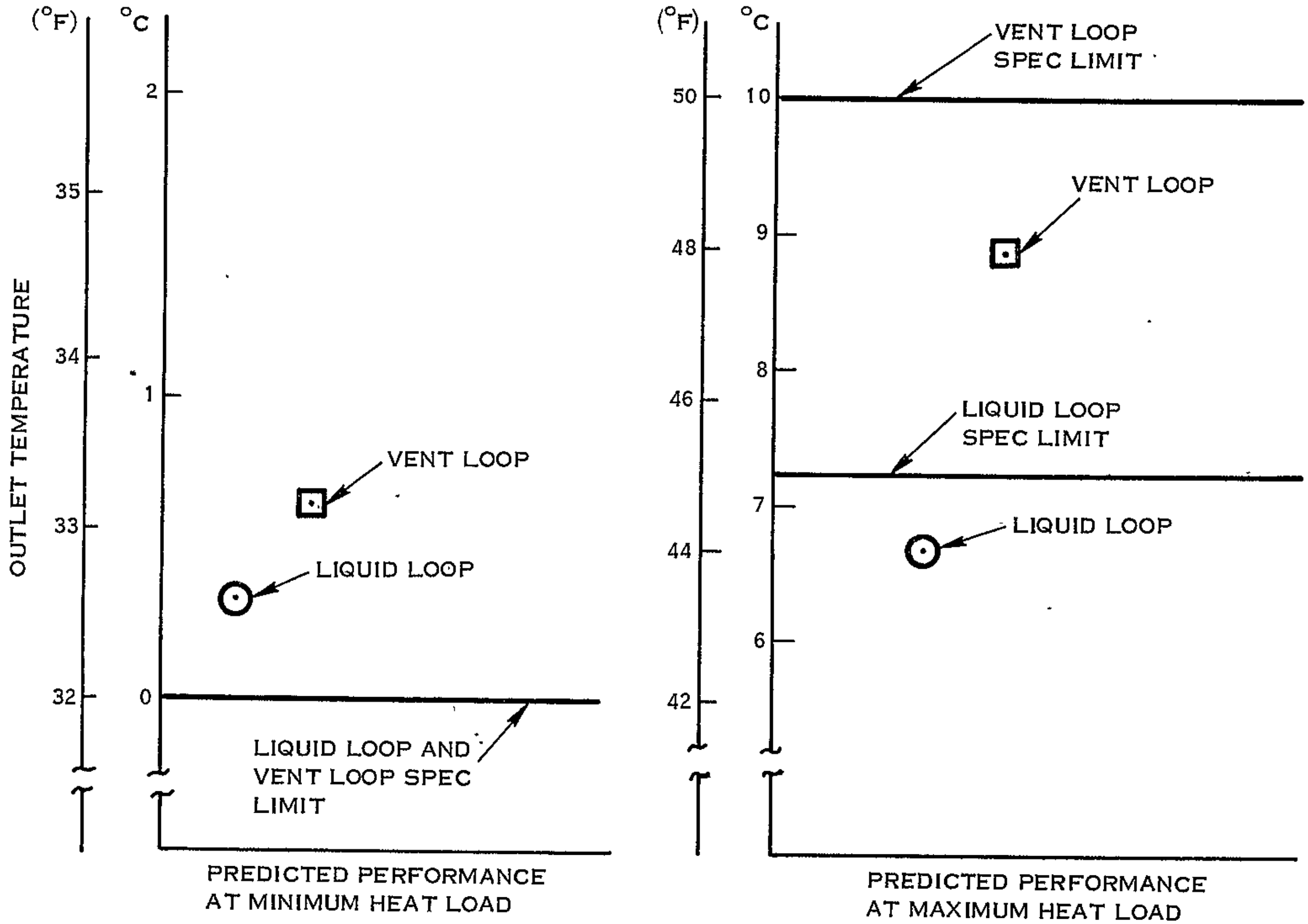
Using the liquid loop and vent loop inlet conditions specified in the mini spec (liquid loop inlet temperature 12.22°C (54°F), vent loop inlet temperature 43.33°C (110°F) and inlet dew point 32.78°C (91°F)), the unit performance would be as shown in Figure 4-9-3; however, in actual use, the liquid loop inlet temperature at maximum load will stabilize at a lower valve than specified with a corresponding decrease in liquid loop and vent loop outlet temperature to 4.44°C (40°F) and 7.78°C (46°F) respectively.

Under the maximum vent loop heat load conditions, the predicted pressure drop is 248 Pa (1" H_2O) versus a maximum allowable of 697 Pa (2.8" H_2O), and under the maximum liquid loop inlet conditions, the predicted pressure drop is 2.827 KPa (.45 psi) versus a maximum allowable of 5.019 KPa (.728 psi).

Figure 4-9-4 is an isometric view of the sublimator showing the overall size and basic configuration. The major elements are the support grid, heat exchanger assembly, porous plate and wire mesh spacer. The support grid and heat exchanger assembly are made of aluminum to minimize the sublimator weight and volume.

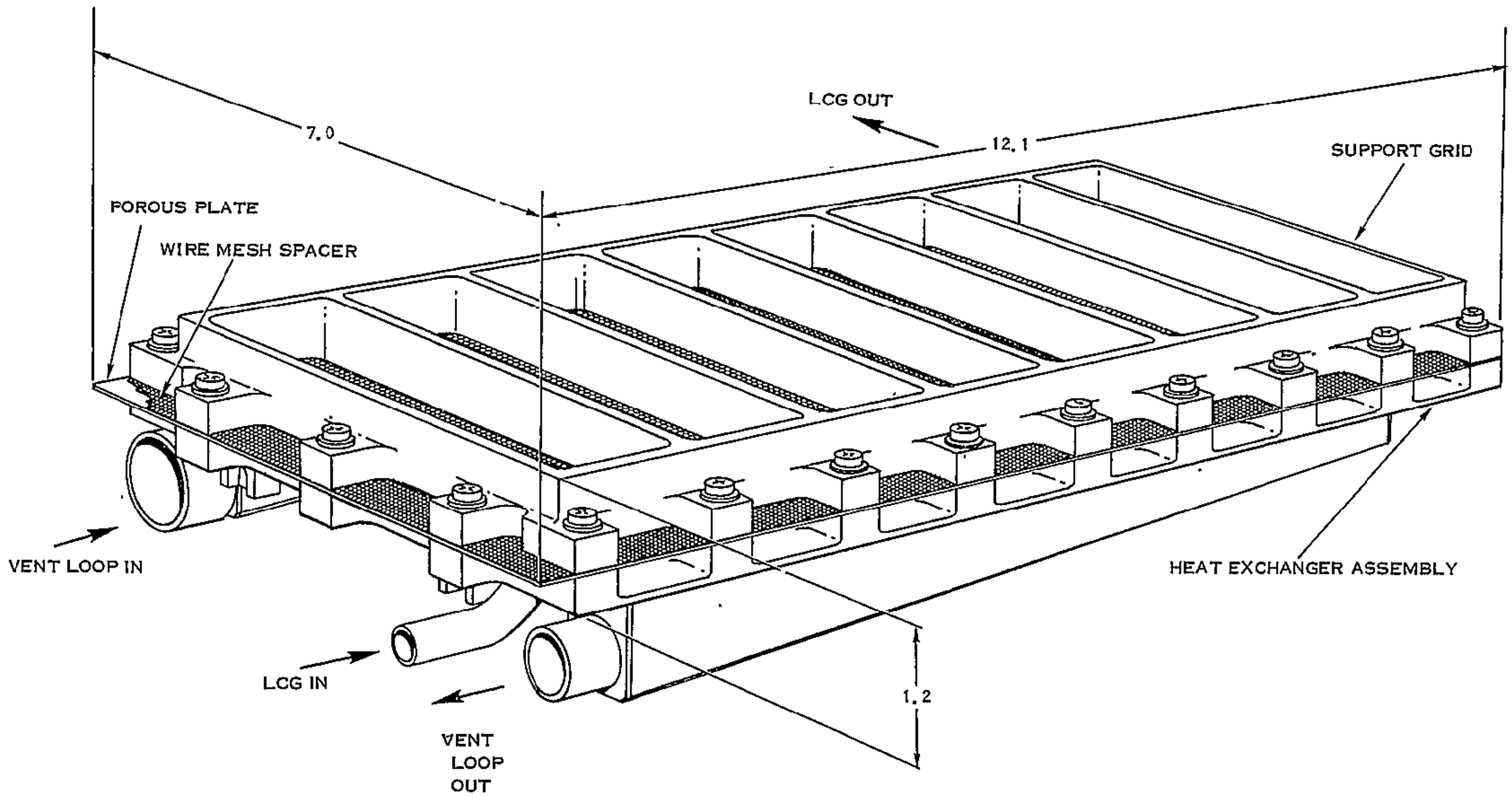
Figure 4-9-5 is a section through the vent loop headers and shows the relative location of the vent loop inlet and exhaust headers, the slurper header and outlet duct, the heat exchanger core and the support grid.

The heat exchanger core, which is comprised of the LCG loop end sheet, LCG loop fins, housing, vent loop fins and the vent loop end sheet is a fluxless brazed assembly to which the various headers are welded. After the heat exchanger is brazed and welded, the upper surface is machined flat, the feed water distribution slots and the 'O' seal groove are added, and the assembly



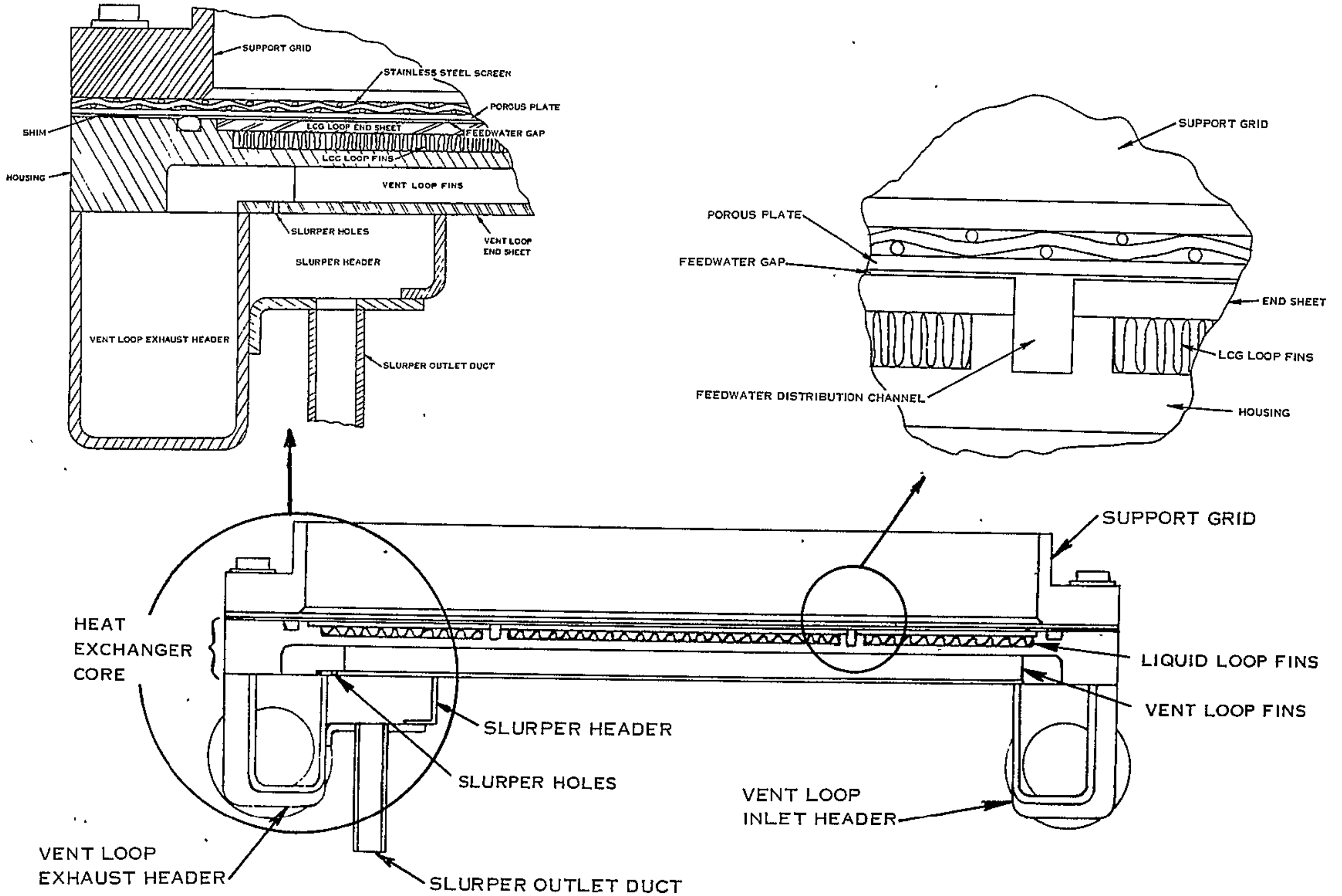
PREDICTED HRS PERFORMANCE

FIGURE 4-9-3



SUBLIMATOR

FIGURE 4-9-4



SUBLIMATOR CROSS SECTION THROUGH VENT LOOP HEADERS

FIGURE 4-9-5

4.9 (Continued)

is anodized for corrosion protection. The feed water gap is established by placing a shim between the heat exchanger housing and the porous plate. The support grid is used to minimize the deflection of the porous plate, and the stainless steel screen is used to minimize the back pressure in the area of the grid to prevent break through. The design of the unit permits easy porous plate removal should it require field replacement or refurbishment.

In operation, the moist vent loop gas enters the unit at the inlet header, passes through the vent loop core and exits at the vent loop exhaust heater. As the gas passes over the vent loop fins, it is cooled by heat transfer to the LCG side of the heat exchanger resulting in condensation of water on the fins. This water and a small amount of the inlet gas is drawn from the vent loop to the slurper header through the slurper holes. From the slurper header, the condensate is delivered to the second stage via the slurper outlet duct. The vent loop fins and inlet and exhaust headers are coated with a hydrophilic coating to assure that the condensed water will flow to the slurper holes.

Figure 4-9-6 is a cross section through the LCG loop headers showing the LCG inlet and outlet tubes, the feed water inlet and the feed water distribution slot.

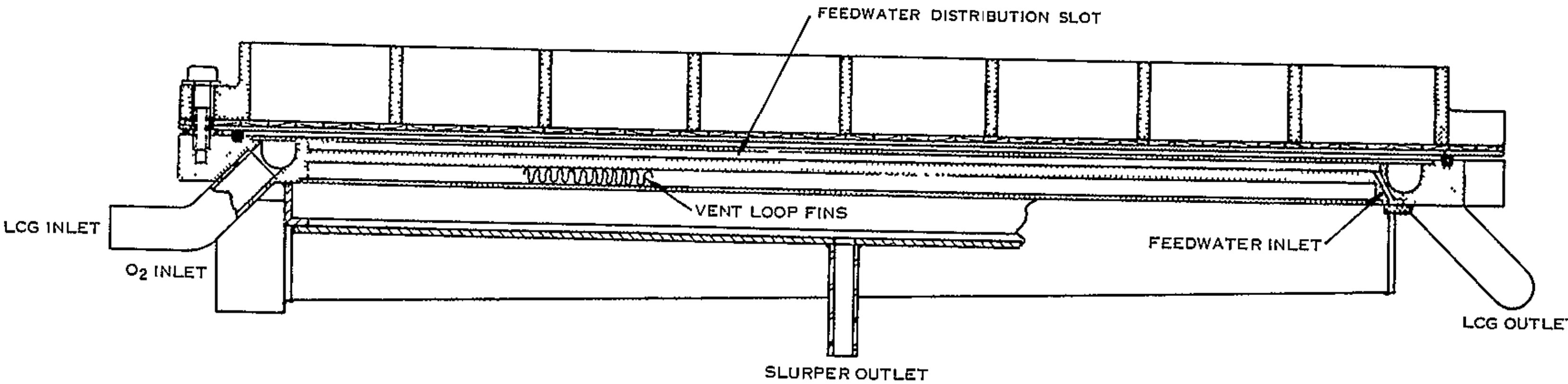
The blown up view depicts the feed water inlet. Feed water enters the unit through the feed water inlet tube and is supplied to the two feed water distribution slots through the channel.

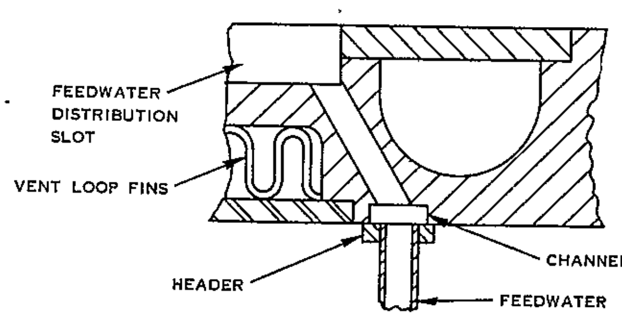
4.10 Humidity Control System Feasibility Tests and Detail Design

The HCS is a two stage device consisting of a first stage slurper which is an integral part of the sublimator and a second stage rotary separator which pumps the condensate into the feedwater circuit. In corporation of the slurper in the sublimator required a test program to establish detail design data.

The slurper tests were conducted using a setup which simulated the TCS heat exchanger as shown in Figure 4-10-1. The fin sample simulated the vent loop portion of the heat exchanger while the water circuit simulated the LCG portion of the heat exchanger. The sides of the fixture were configured to simulate the flow path in the inlet and outlet headers and were made of plexiglass so that the performance of the slurper could visually be observed. In a typical test run, heated and moisturized gas was introduced at the inlet, the moisture was condensed in the fin sample and was withdrawn through the slurper holes, while the cooled gas was exhausted through the outlet.

The performance was evaluated at each expected operating pressure 27.58 KPa (4.0 psia), 101.35 KPa (14.7 psia), 128.93 KPa (18.7 psia)

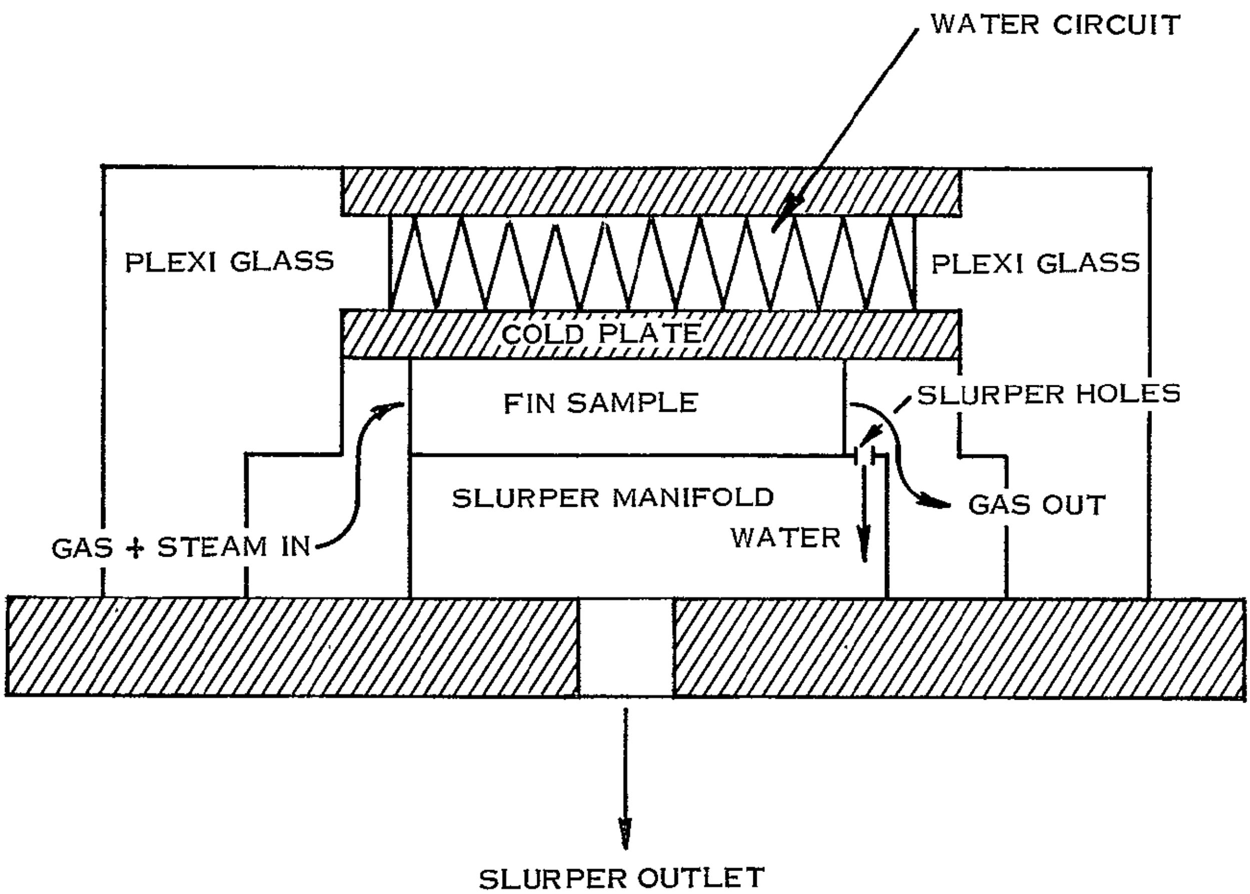




FEEDWATER INLET DETAILS

SUBLIMATOR CROSS SECTION THROUGH LIQUID LOOP HEADERS

FIGURE 4-9-6



TCS SLURPER TEST FIXTURE AND SAMPLE

FIGURE 4-10-1

4.10 (Continued)

At each operating pressure, the vent flow was set at values of 16.45 x 10-4 m^3/ sec (3.5 acfm), 25.5 x 10-4 m^3/sec (5.5 acfm), 32.9 x 10-4 m^3/sec (7 acfm), and at each vent flow, the slurper delta P was varied from 995 Pa (4" H_2O) to 248 Pa (1" H_2O). Initial testing was conducted using a .25 inch spacing of the slurper holes (spacing utilized in TCS design), and subsequent testing conducted with hole spacing increased to .5 inch. In all cases, there was no visible water carry-over indicating that the slurper will function over a wide range of operating conditions. These results are summarized in Figure 4-10-2.

The system evaluation identified a fan motor powered rotary separator as the optimum second stage separator. To demonstrate the feasibility of coupling the fan and separator, the separator was designed to be coupled to an Apollo PLSS fan volute and rotor and powered by a motor capable of running with a gas loop pressure of 25 KPa (3.7 psig) to 129 KPa (18.7 psia) (reference SVSK 87343). A cross section of this device is depicted in Figure 4-10-3.

In operation, water enters at the separator inlet and is slung to the surface of the rotary drum. The water is forced by centripital acceleration into the trough and is pumped from the separator when it enters the hole in the stationary pitot. The gas which enters at the separator inlet exits the rotary drum and mixes with the vent loop inlet gas prior to entering the fan rotor/volute region of the device.

4.11 Water Management Subsystem and Thermal Control System Detail Design

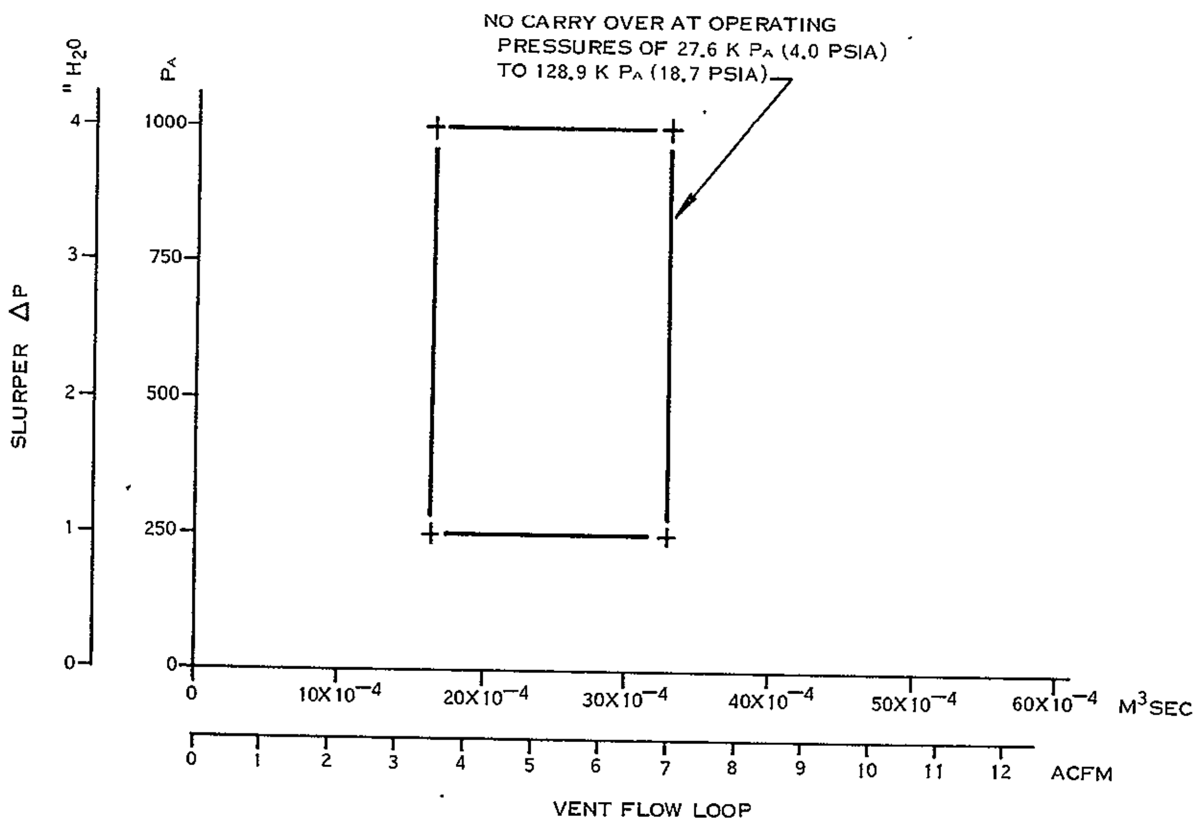
Figure 4-11-1 is a schematic of the delivery Thermal Control System (reference SVSK 87319) which is comprised of a Heat Rejection Subsystem (sublimator), Water Management Subsystem (WMS), and Humidity Control Subsystem (slurper and rotary separator).

The sublimator and rotary separator were previously discussed. All other items shown make up the Water Management Subsystem (WMS) which is comprised of commercial stainless steel shutoff valves, relief valves, an Apollo PLSS canister reservoir, fill and drain connectors, check valve and an auxiliary reservoir which has been reworked to reduce the volume to that of the bubble expansion tank.

To provide corrosion protection, all plumbing is either stainless steel or tygon tubing, and all aluminum parts in contact with water are coated with an epoxy ester.

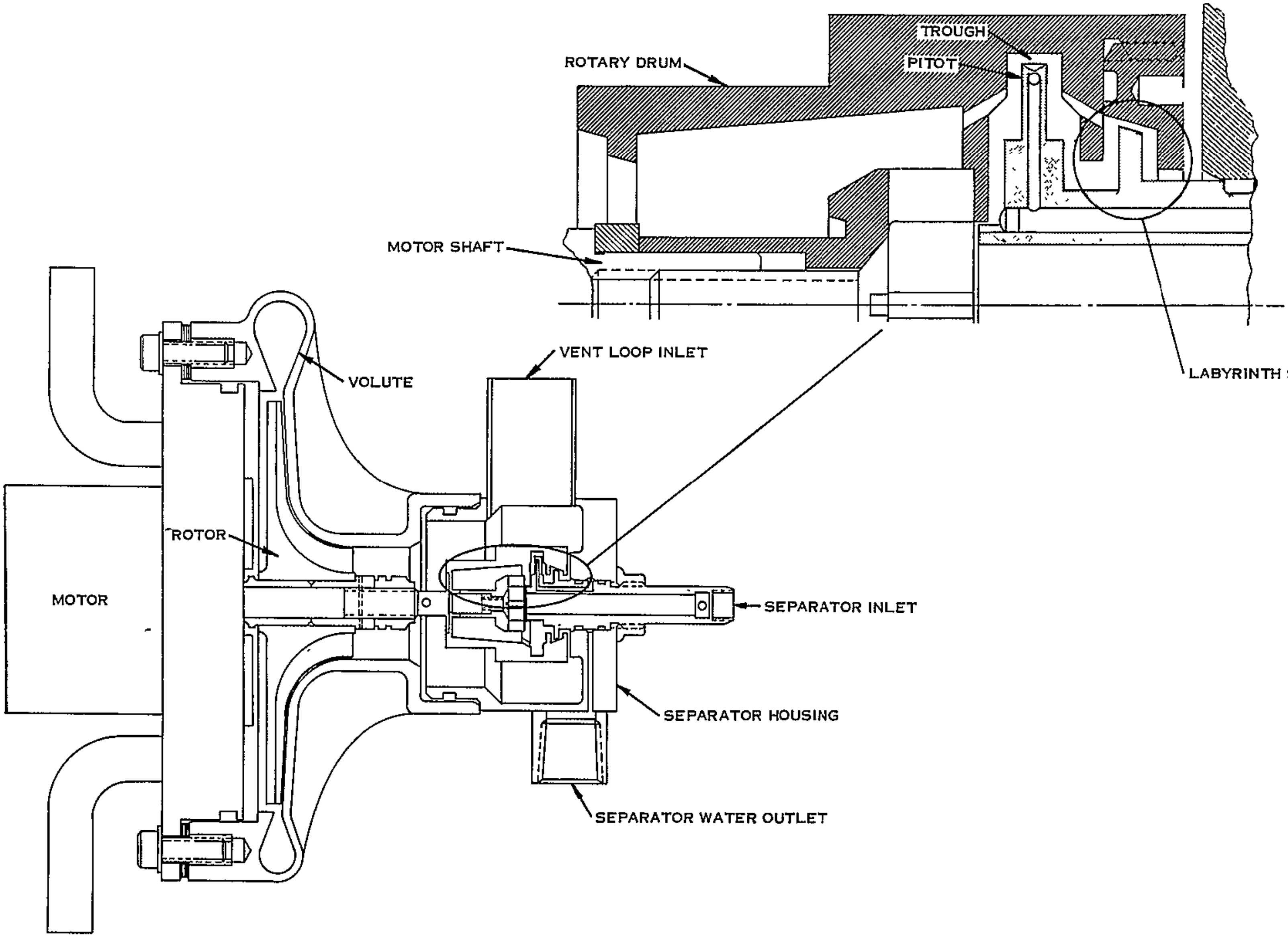
The bubble expansion tank (SVSK 87332) was sized to accommodate the gas released when the pressure in the main reservoir, which holds 4.1 Kg (9 lbs) of water, is reduced from 248 KPa (36 psia) to 27.6 KPa (4 psia) while also accommodating the condensate generated during a one-half hour pre-EVA check out. The volume required to accommodate the free gas was determined using the following relationships:

C-2



SLURPER PERFORMANCE SUMMARY

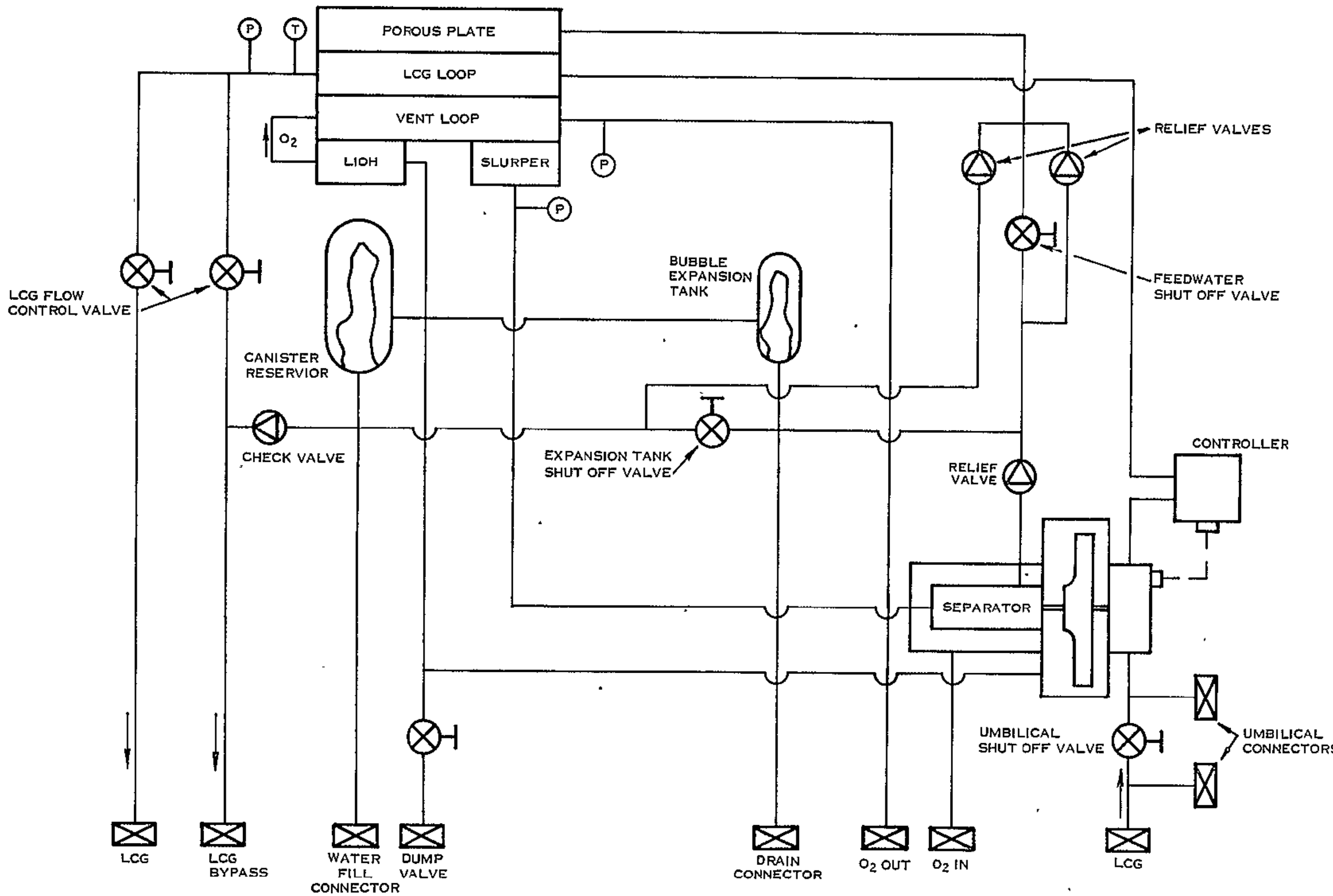
FIGURE 4-10-2



FAN/ROTARY SEPARATOR

FIGURE 4-10-3

Hamilton Standard
DIVISION OF UNITED AIRCRAFT CORPORATION



TCS SCHEMATIC

FIGURE 4-11-1

4.11 (Continued)

$$\dot{M}_{free} = \dot{M}_{initial} - \dot{M}_{final} \text{ and } \dot{M} = \frac{PV}{RT}$$

where $\dot{M}_{free}$ = mass of the free gas

$\dot{M}_{initial}$ = the mass of the gas dissolved in the water at 248 KPa (36 psia)

$\dot{M}_{final}$ = the mass of the gas dissolved in the water at 27.6 KPa (4 psia)

P = pressure

V = volume of gas

R = gas constant of the dissolved gas

T = temperature of the dissolved gas

Substituting $\frac{PV}{RT}$ for $\dot{M}$ yields:

$$\frac{P_{free}\,V_{free}}{R_{free}\,T_{free}} = \frac{P_{initial}\,V_{initial}}{R_{initial}\,T_{initial}} - \frac{P_{final}\,V_{final}}{R_{final}\,T_{final}}$$

Assuming the temperature remains relatively constant, this reduces to:

$$P_{free}\,V_{free} = P_{initial}V_{initial} - P_{final}\,V_{final}$$

where $P_{free} = P_{final}$ = the final pressure in the reservoir

$V_{initial} = V_{final} = V_{saturated}$ = the volume of the saturated gas in the water which is equal to a saturation factor times the volume of the water.

V_{free} = the volume of the free gas

thus

$$V_{free} = V_{saturated}\left(\frac{P_{initial}-P_{final}}{P_{final}}\right)$$

or

$$V_{free} = V_{saturated}\left(\frac{P_{initial}}{P_{final}} - 1\right)$$

4.11 (Continued)

The worst case saturation factor is .026 (reference 3). Thus, a minimum of 852 cc (52 in^3) is required to accommodate the gas released when pressure on the 4.1 Kg (9 lb) of water contained in the reservoir is dropped from 248 KPa (36 psia) to 27.6 KPa (4 psia).

Assuming the work rate during pre-EVA check out is approximately 1/2 the average work rate, the condensate generated is equal to:

$$1/2 \times \frac{.77 \text{ Kg } (1.7 \text{ lb})}{4.5 \text{ hours}} \times 1/2 \text{ hour or } .04 \text{ Kg } (.09 \text{ lbs})$$

This is equivalent to a volume of 43 cc (2.6 in^3). Therefore, to accommodate the free gas plus the condensate generate during the pre-EVA check out the minimum volume is 852 cc (52 in^3) + 43 cc (2.6 in^3) or 895 cc (54.6 in^3). Since the bladder tanks have an expulsion efficiency of about 96%, the minimum bubble expansion tank volume is:

$$\frac{895^{cc} \ (54.6 in^3)}{.96} = 932 \text{ cc } (56.9 \text{ in}^3)$$

In the case of a flight design, the required bubble expansion tank volume would be reduced because the main tank would be smaller than the Apollo PLSS reservoir which was used in the TCS. The actual size of the main reservoir would be dependent upon how much separated water could be used as feed water. Figure 4-11-2 shows the volume of a flight expansion tank and reflects the decreasing volume required as the main reservoir volume is reduced because of increased utilization of the separated water. If it is assumed that the bubble expansion tank must store all the condensate generated during a 4.5 hour EVA in the non venting mode, the minimum allowable bubble expansion tank volume is 80 cc (48.8 in^3) no matter what the utilization of the condensate as is shown in Figure 4-11-2.

Figure 4-11-3 shows how the volume of Apollo PLSS auxiliary reservoir reduced to that of the bubble expansion tank. The outer shell rework consists of removing a segment of the tank wall and rewelding the two halves. The upper bladder restraint has been changed as shown to simplify the clamping details and to eliminate the possibility of cutting the bladder with the assembly tools. The bladder rework consists of removing a segment and then bonding the two halves with RTV 102. A portion of the segment removed from the bladder is bonded as shown to reinforce the joint.

3) Standard Handbook for Mechanical Engineers, Theodore Baumeister, Editor, McGraw-Hill Book Company, Seventh Edition, 1967, Page 6-6.

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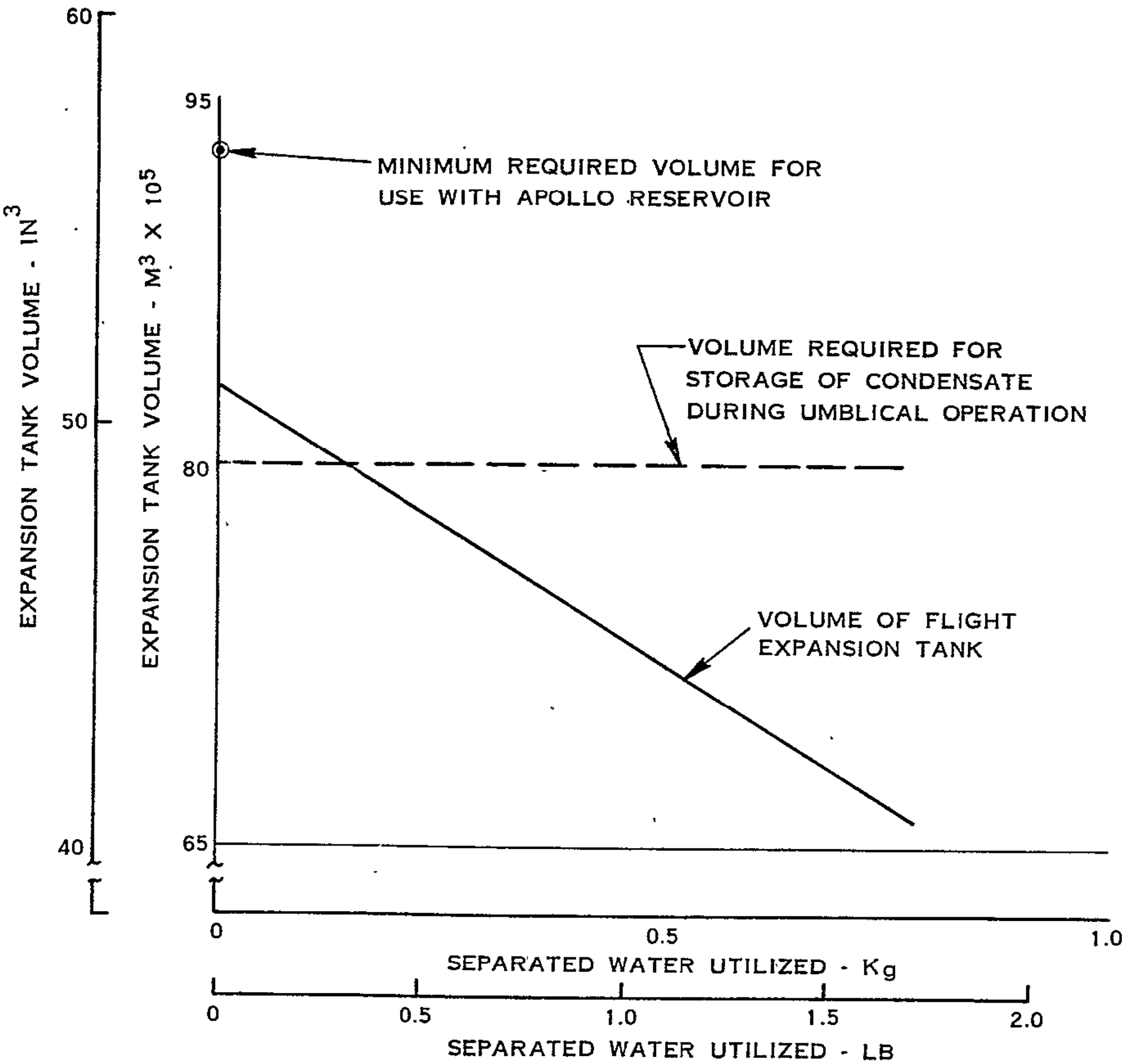
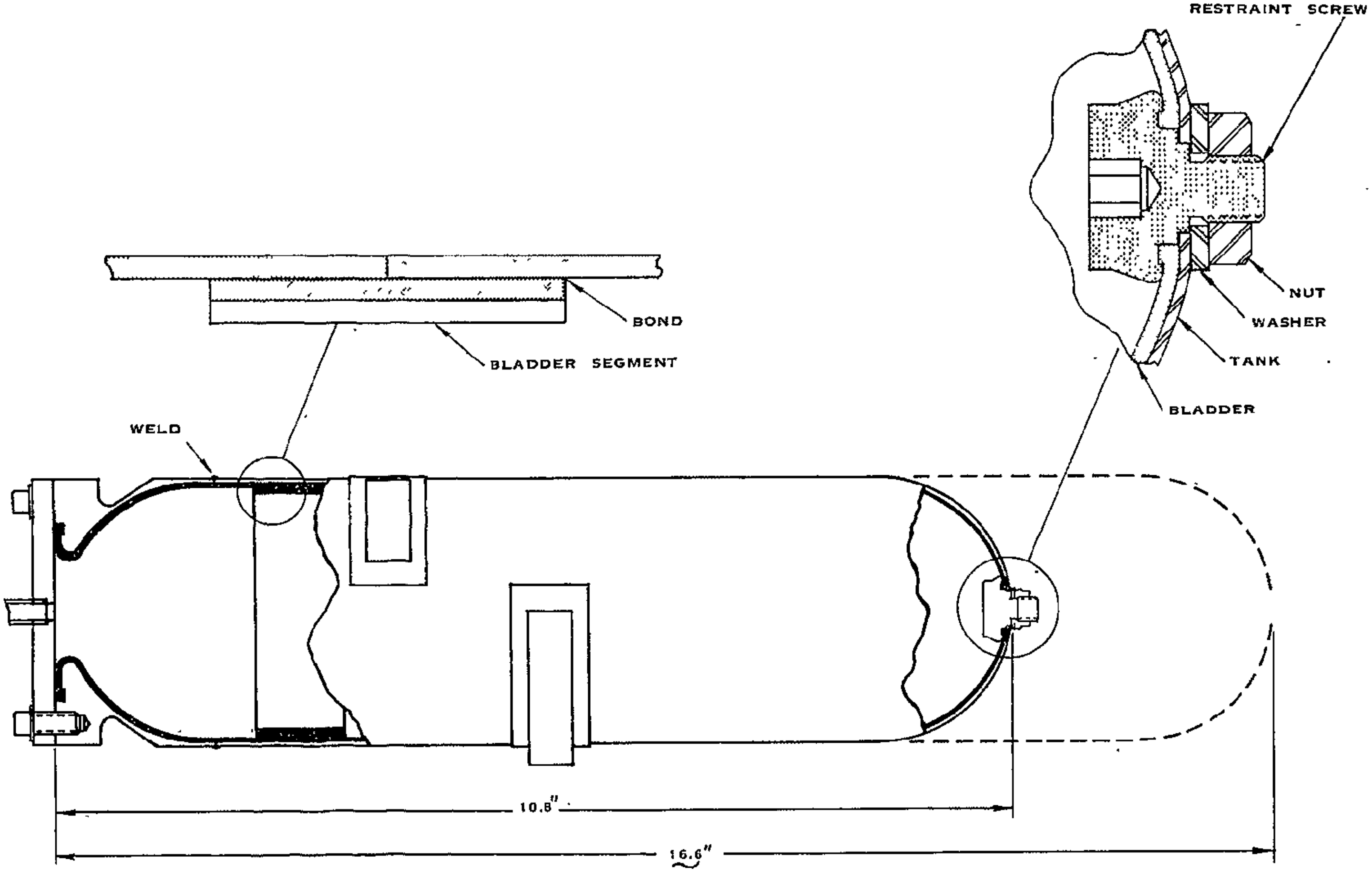


BUBBLE EXPANSION TANK VOLUME
VERSUS SEPARATED WATER UTILIZED AS FEEDWATER
FIGURE 4-11-2



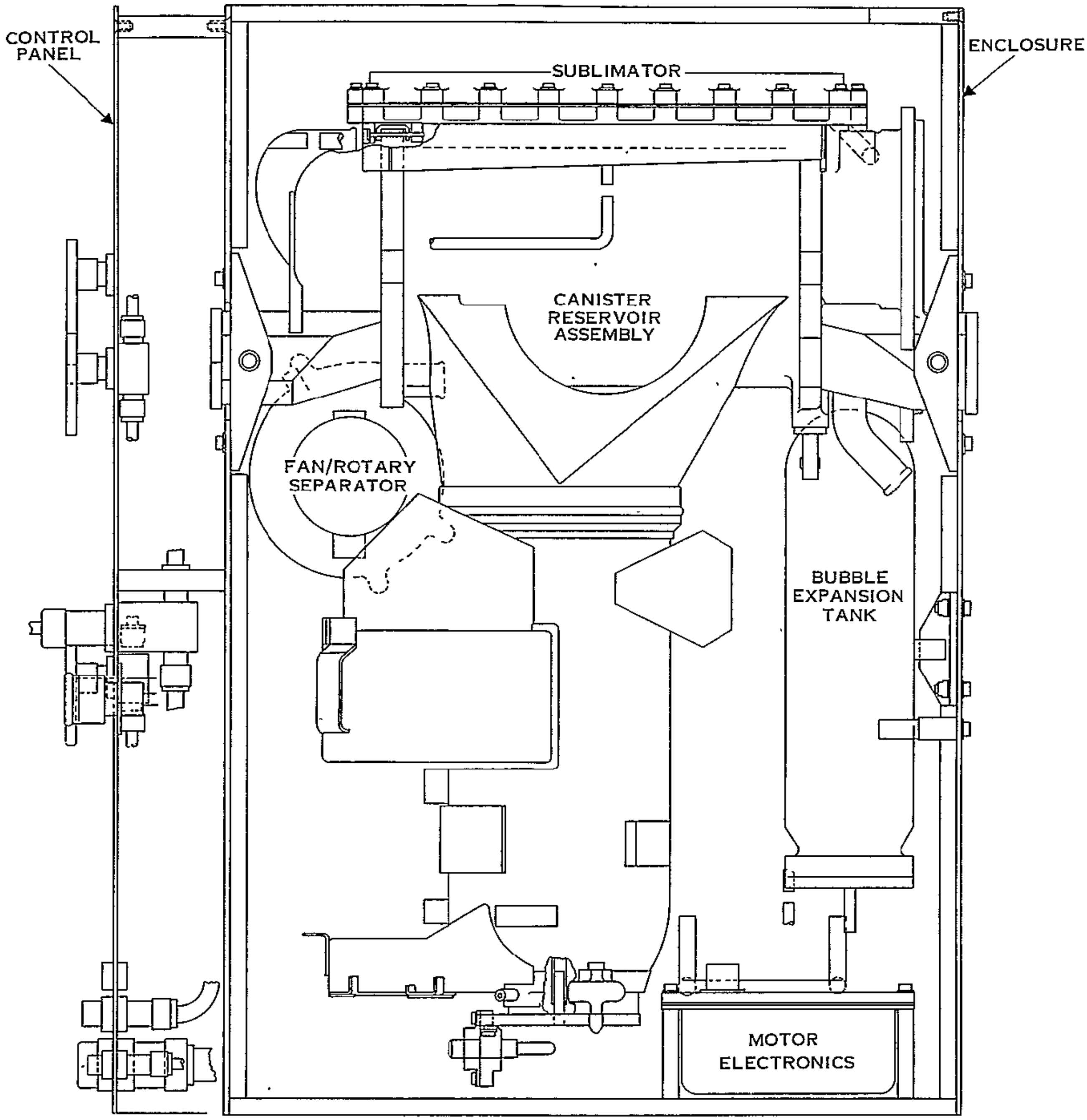
BUBBLE EXPANSION TANK

FIGURE 4-11-3

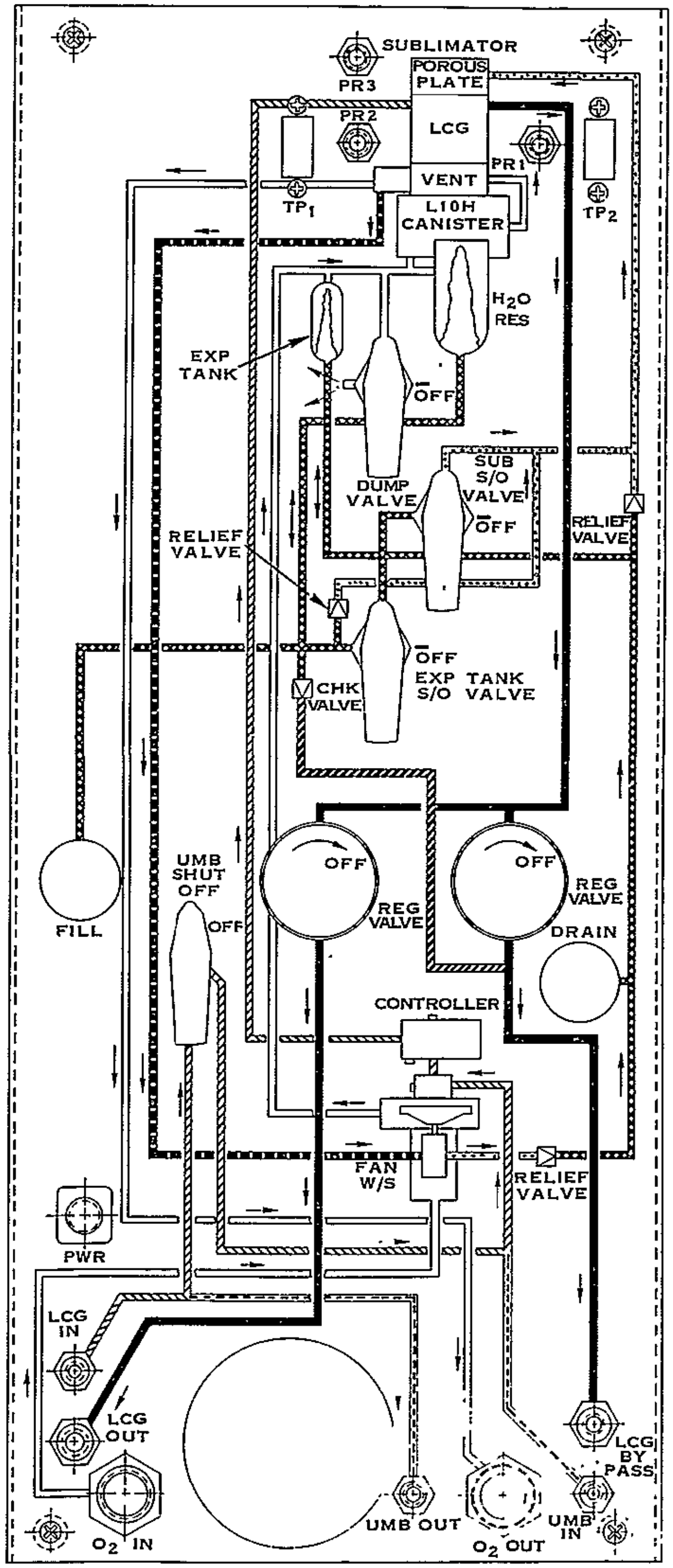
4.11 (Continued)

The system will be packaged as shown in Figure 4-11-4. The enclosure is made up of aluminum panels which are painted white.

The sublimator and fan/rotary separator are mounted on the canister reservoir which is, in turn, attached to the enclosure side and bottom panels. The bubble expansion tank and motor electronics are attached to the enclosure panels as shown. All shutoff valves, quick disconnects, interface fittings and relief valves are located on the control panel as shown in Figure 4-11-5. The control panel will also contain a complete schematic as shown in Figure 4-11-5.



TCS PACKAGING
FIGURE 4-11-4



VIEW OF CONTROL PANEL
FIGURE 4-11-5

5.0 Conclusions

The TCS study has involved the least cost, least weight, least complex and most reliable system for providing thermal control for the Shuttle Extravehicular Life Support System. This system is comprised of a replaceable plate sublimator heat rejection subsystem, a bubble expansion tank water management subsystem, and a two stage humidity control subsystem consisting of a first stage slurper and a second stage fan motor powered rotary separator.

The hardware designs summarized in this report represent significant improvements over the comparable hardware used in the Apollo PLSS. These designs, which are supported by actual performance data, are lighter, require less power, are longer life and more maintainable and less costly than hardware serving a similar function in the Apollo PLSS.

APPENDIX A

SHUTTLE EVLSS THERMAL CONTROL SYSTEM

MINI SPECIFICATION

SHUTTLE EVLSS
THERMAL CONTROL SYSTEM (TCS)
"MINI" SPECIFICATION

1.0 INTRODUCTION

This "mini" specification defines the requirements for a Space Shuttle Extravehicular Life Support System (EVLSS) Prototype Thermal Control System (TCS) which consists of a Heat Rejection Subsystem (HRS), a Water Management Subsystem (WMS), and a Humidity Control Subsystem (HCS).

2.0 APPLICABLE DOCUMENTS

MIL-STD-810B	Environmental Test Methods
MSCM-8080	Manned Spacecraft Criteria and Standards
MSC-SPEC-SD-W-0020	Potable Water Specification

3.0 REQUIREMENTS

3.1 Performance

3.1.1 Heat Rejection Subsystem

The Heat Rejection Subsystem (HRS) will use water as an expendable and will provide cooling for the oxygen loop and the liquid cooling loop of the EVLSS.

3.1.1.1 Oxygen Loop Parameters

3.1.1.1.1 Operating Pressure

The normal operating pressure within the oxygen loop will be 25.5-27.6 KPa (3.85 ± .15 psid) above ambient pressure. The unit must be capable of withstanding a pressure of 29.3 KPa (4.25 psid) and a collapsing pressure of up to 101 KPa (14.7 psia).

3.1.1.1.2 Maximum Heat Load

The HRS shall cool the oxygen loop to 10°C (50°F) maximum with the inlet conditions of 2.6×10^{-3} m^3/sec (5.5 ACFM) flow, 25.5 to 27.6 KPa (3.85 ± 0.15 psia) pressure, 43.33°C (110°F) temperature and dew point of 32.78°C (91°F).

3.1.1.1.3 Minimum Heat Load

The HRS shall cool the oxygen without freezing the condensed water with inlet conditions of 2.6 x 10^{-3} m^3/sec (5.5 ACFM) flow, 25.5 to 27.6 KPa (3.85 ± 0.15 psia) pressure, 22.22°C (72°F) temperature, and a dew point of 1.67°C (35°F).

3.1.1.1.4 Pressure Drop

The pressure drop in the oxygen loop shall not exceed 694 Pa (2.8 inches of water) under the conditions established in paragraph 3.1.1.1.2.

3.1.1.2 Liquid Loop Parameters

3.1.1.2.1 Operating Pressure

The normal operating pressure within the liquid loop will be 24.1 to 157.5 KPa (3.50 to 22.85 psia). The maximum normal pressure (non-operating) will be 246 KPa (35.7 psia).

3.1.1.2.2 Maximum Heat Load

The HRS shall cool the water loop to 7.22°C (45°F) maximum with inlet conditions of .03 Kg/sec (4.0 lb/min) flow and 12.22°C (54°F) temperature.

3.1.1.2.3 Minimum Heat Load

The HRS will cool but not freeze the water loop with an inlet heat load of 42 watts (144 Btu/hr) under the minimum flow conditions of the system. The maximum inlet temperature will be up to 26.67°C (80°F) depending upon selected concept.

3.1.1.2.4 Pressure Drop

The pressure drop in the water loop shall not exceed 5 KPa (.728 psi) with an inlet flow of .03 Kg/sec (4.0 lb/min) and an inlet temperature 7.22 to 12.78°C (45-55°F).

3.1.1.3 Start Up and Shutdown Requirements

3.1.1.3.1 Controls

As a design goal, the HRS shall be started up and shutdown by a single control. A special start up position shall not be required.

3.1.1.3.2 Spillage

There shall be no water spillage when started up for each EVA. (Dry out within the prescribed shutdown period (five minutes) fulfills this intent.)

3.1.1.3.3 Start Up Time

The HRS shall be capable of rejecting the maximum heat load and meeting the performance requirements of paragraph 3.1.1.2.2 within 10 minutes after being turned on with a design goal of five minutes.

3.1.1.3.4 Shutdown Time

The HRS shall be non-venting within five minutes after shut-off in a hard vacuum environment.

3.1.1.3.5 Start Up Conditions

3.1.1.3.5.1 Liquid Loop

The HRS shall be capable of start up with liquid loop temperatures from 10.0 to 37.78°C (50 to 100°F) and flow rate of .001 to .03 Kg/sec (.14 to 4 lb/min).

3.1.1.3.5.2 Oxygen Loop

The HRS shall be capable of start up with oxygen loop conditions of 10.0 to 37.78°C (50 to 100°F), dew point of 1.67 to 29.44 °C (35 to 85°F), pressure of 25.5 to 27.6 KPa (3.85 $\pm$ .15 psia), and a flow rate of 2.6×10^{-3} m^3/sec (5.5 ACFM).

3.1.1.3.5.3 Expendable Water Circuit

The HRS shall be capable of start up expendable water supplied at the following conditions:

a. Temperature Range: 1.67 to 37.78°C (35 to 100°F)
b. Pressure Range: 25.5 to 246 KPa (3.70 to 35.7 psia)

Depending on the type of WMS and HRS, the expendable water may be fully saturated with N_2 and H_2 to a partial pressure of 3.33 KPa (25 mm Hg).

NOTE: The pressure range is based on vehicle imposed pressure on the WMS. In the event a higher or lower pressure is required to operate the HRS, the pressure range will be adjusted accordingly.

3.1.1.4 Maintenance

The HRS shall be capable of storage for 24 hours minimum at hard vacuum with no special preparation necessary to make it ready for an EVA cycle other than replenishing the expendable water supply. The HRS shall also be capable of start up, two hours operation, shutdown, and non-venting (non-operating) for 30 minutes, start up and 1 1/2 hours operation and final shutdown.

The HRS shall be capable of operating while being wetted during a mission cycle lasting up to 30 days before requiring any special servicing.

3.1.2 Water Management Subsystem

The WMS shall supply expendable water to the HRS as required and makeup water to the liquid cooling loop as required. The WMS may accept and store or use separated water from the HCS.

3.1.2.1 Fluid Capacity

3.1.2.1.1 Expendable Water

The reservoir shall be capable of holding a minimum of 3.45 Kg (7.6 pounds) of water when charged and of leaving a minimum amount of residual water when no longer capable of supplying water.

3.1.2.1.2 Separated Water

Water separated from the oxygen loop by the HCS may be stored or used as expendable water.

3.1.2.2 Fluid Pressure

3.1.2.2.1 Expendable water will be provided to the WMS at a pressure of 124 to 246 KPa (18 to 35.7 psia). As a design goal, the system shall be capable of working with water at 386 KPa (56 psid). After start up, the water pressure supplied to the HRS may be 25.5-27.6 KPa (3.85 ± .15 psid) depending on the HRS concept selected.

3.1.2.2.2 Separated Water

The separated water pressure will be TBD above ambient pressure. The expected pressure is 23-30 KPa (3.85 ± .5 psid).

3.1.2.3 Fluid Temperature

3.1.2.3.1 Expendable Water

The expendable water will be provided to the WMS at a temperature of 1.67 to 37.78°C (35 to 100°F).

3.1.2.3.2 Separated Water

The separated water temperature will be .56 to 32.22°C (33 to 90°F).

3.1.2.4 Fluid Processing

With the possible exception of removing gasses, the WMS shall not process the water to be supplied to the HRS.

3.1.2.5 Contamination

The WMS shall not add contamination to the water to be supplied to the HRS.

3.1.3 Humidity Control System

The HCS will separate the condensed water from the oxygen loop portion of the HRS heat exchanger and will either store the water or deliver it to the WMS for storage or use as an expendable.

3.1.3.1 Storage Capacity

If the HCS stores the separated water, it shall be capable of holding a minimum of .77 Kg (1.7 lbs) of water, and it shall have drain provisions.

3.1.3.2 Separation Rate

The HCS shall separate a minimum of 5.3×10^{-5} Kg/sec (0.42 lb/hr) of condensate from the oxygen loop portion of the HRS.

3.1.3.3 Slugging

The HCS shall either prevent condensate slugging, or it shall be insensitive to slugging.

3.1.3.4 Orientation

The HCS shall separate water in any orientation with respect to gravity.

3.1.3.5 Oxygen Loop Parameters

The pressure drop of the oxygen loop portion of the HCS shall not exceed 89.6 Pa (0.36 inches of water) with oxygen loop flow of 2.6×10^{-3} m^3/sec (5.5 ACFM), temperature in the range of 40 to 90°F, and pressure in the range of 25.5-27.6 KPa (3.85 ± 0.15 psia).

3.1.4 Relief Valve

The TCS shall incorporate a relief valve in the expendable water circuit. The valve shall be set at TBD.

3.1.5 Check Valve

The WMS shall contain a check valve to prevent water flow from the liquid cooling loop to the expendable water circuit.

3.1.6 Umbilical Operation

The TCS shall also be capable of being used with the HRS shutdown and connected to a spacecraft liquid cooling umbilical to provide cooling to both the vent loop and liquid cooling garment for a period of 4.5 hours. The TCS shall operate and remain safe, but may operate with selected degraded performance, when operated with a spacecraft liquid umbilical.

3.2 Useful Life

The useful life shall be a minimum of 100 mission cycles or 15 years, including up to 25,000 hours of mission related wet storage. The TCS will meet the requirements of this spec during its entire useful life. Replacement of limited life items is permitted during ground check out and maintenance operations during the useful life, but the limited life items shall be selected to meet the useful life requirements wherever feasible. Limited life item maintenance will not be permitted during orbital operations.

3.2.1 Mission Cycle

A mission cycle includes the following operations of an EVLSS with the TCS installed: preinstallation check out, installation in vehicle, launch, orbital operations including up to six EVA cycles, deorbit, landing, removal from vehicle, and post flight check out and maintenance.

3.2.2 EVA Cycle

An EVA cycle includes the following operations of an EVLSS with the TCS installed: removal from vehicle stowage, donning, pre-EVA check out, start up, degrees from vehicle, return, shutdown, doffing, recharge of consumables, and stowage in vehicle. There may be as many as 600 EVA cycles during the useful life of the TCS.

3.2.3 Maintenance

Ther shall be no maintenance between EVA cycles in a mission other than recharge of expendable water and discharge of separated water. Ground servicing between missions shall be limited to 24 hours maximum, but shall include cleanliness verification/cleaning and performance check out as a minimum. Minimum maintenance and servicing shall be a design goal while still testing for all potential problems. Recharge of the TCS shall not require tools.

3.3 Natural Environments

The TCS will be packaged for all ground handling, shipping, and storage to protect it from the more severe earth environments such as rain, hail, sand, and duct, etc. The TCS will be designed to withstand the following environmental requirements:

Temperature	Transportation -42.78 to 71.11°C (-45 to +160°F) Storage -37.22 to 43.33°C (-35 to 110°F)
Pressure	0 to 103.4 KPa (0.0 to 15.0 Psia)
Humidity	0-100% R.H.
Sand and Dust	Per Method 510 Procedure I of MIL-STD-810B
Salt Fog	Per Method 509 Procedure I of MIL-STD-810B
Fungus	Per Method 508 Procedure I of MIL-STD-810B
Acoustic Noise	N/A
Gas	Sea Level Ambient to 95 ± 5% by Weight Pure Oxygen

3.3 (Continued)

The environmental requirements are not imposed on the prototype TCS construction but must be met in the design of production TCS's. The differences between the prototype TCS and the production design shall be analyzed and reported. If production design is questionable in meeting any of the requirements, the prototype TCS shall be constructed such that tests can be performed to verify conformance to the requirement.

3.4 Induced Environments

3.4.1 Operating Fluids

3.4.1.1 Liquid Cooling Loop

The water in the liquid cooling loop will be per MSC Spec SD-W-0020, saturated with nitrogen and may include a bactericide. Depending on the TCS configuration, the liquid cooling loop could also contain some separated water.

3.4.1.2 Oxygen Loop

The oxygen loop operating fluid will be oxygen containing water vapor, carbon dioxide, and conductive and corrosive salts produced by the human body.

3.4.1.3 Separated Water

The separated water will come from the oxygen loop and may contain conductive and corrosive salts. It will be saturated with gas.

3.4.1.4 Expendable Water

Expendable water obtained from the vehicle will be per MSC Spec SD-W-0020, except total solids shall be 3.5 mm/liter maximum and may be saturated with N_2 and may contain H_2 at a partial pressure of 3.33 KPa (25 mm Hg) and may include a bactericide. Depending on TCS configuration, the separated water may also be used as an expendable.

3.4.2 Environments

The TCS shall withstand the following environments induced by the spacecraft:

3.4.2 (Continued)

Temperature	1.67 to 37.78°C (35 to 100°F)
Pressure	0 to 103.4 KPa (0.0 to 15.0 Psia)
Humidity	0 to 100% R.H.
Gravity	0.0 to 1.0 G's
Vibration	Lift-off, transonic and q max - Acceleration spectrial density increasing at the rate of +9 dB/octave from 20 to 100 H_z; steady at 1 g^2/H_z to 250; decreasing at the rate of -6 dB/octave from 250 to 2,000 H_z. The vibration occurs for a duration of 70 seconds per flight.
Impact Shock	Normal leading 3.3 g saw tooth pulse with a rise time of 10 to 11 milliseconds and a decay time of 0 to 1 millisecond. Crash 20 g saw tooth pulse with a rise time of 10 to 11 milliseconds and a decay time of 0 to 1 millisecond. Unit need not operate subsequently.
Acceleration	$\pm$ 3 g's maximum

The environmental requirements are not imposed on the prototype TCS construction but must be met in the design of production TCS's. The differences between the prototype TCS and the production design shall be analyzed and reported. If production design is questionable in meeting any of the requirements, the prototype TCS shall be constructed such that tests can be performed to verify conformance to the requirement.

3.5 Design

3.5.1 Structural Requirement

3.5.1.1 Proof Pressure

NOTE: The proof pressure shall be 1.5 times the maximum operating or relief valve pressure and shall be held for a minimum of five minutes.

3.5.1.1.1 Oxygen Loop

The oxygen loop shall be capable of operating within the requirements of this specification after being subjected to 41.3 KPa (6.0 psig) for five minutes.

3.5.1.1.2 Expendable Water Circuit

The expendable water circuit, with the water shutoff valve closed, shall be capable of operating within the requirements of this specification after being subjected to TBD KPa (TBD psig), upstream of the shutoff valve for five minutes.

The expendable water circuit loop, with the water shutoff valve open, shall be capable of operating within the requirements of this specification after being subjected to TBD KPa (TBD psig) for five minutes.

3.5.1.1.3 Water Separator Drain Loop

The water separator drain loop, with the water shutoof valve closed, shall be capable of operating within the requirements of this specification after being subjected to TBD KPa (TBD psig), downstream of the shutoff valve for five minutes.

3.5.1.1.4 Liquid Loop

The liquid loop shall be capable of operating within the requirements of this specification after being subjected to 620 KPa (90 psig) for five minutes.

3.5.1.2 Burst Pressure

3.5.1.2.1 Oxygen Loop

NOTE: The burst pressure shall be 2.0 times the maximum operating or relief valve pressure and shall be held for a minimum of five minutes. The oxygen loops shall not rupture but may permanently deform when subjected to 55.1 KPa (8.0 psig).

3.5.1.2.2 Expendable Water Circuit

The expendable water circuit, with the water shutoff valve closed, shall not rupture but may permanently deform when subjected to TBD KPa (TBD psig) upstream of the shutoff valve.

The expendable water circuit, with the water shutoff valve open, shall not rupture but may permanently deform when subjected to TBD KPa (TBD psig).

3.5.1.2.3 Water Separator Drain Loop

The water separator drain loop, with the water shutoff valve closed, shall not rupture but may permanently deform when subjected to TBD KPa (TBD psig) downstream of the shutoff valve.

3.5.1.2.4 Liquid Loop

The liquid loop shall not rupture but may permanently deform when subjected to TBD KPa (TBD psig).

3.5.2 Weight and Volume

The TCS size and weight must be minimized in order to be part of an extravehicular life support system worn by a crewman. The size and weight requirements are not imposed on the prototype TCS but must be met in designing production or flight TCS's. The differences between the prototype TCS and the production design shall be analyzed and reported. If the size and weight are important factors in meeting the requirements of this SOW, then the prototype TCS shall be constructed such that tests can be performed to verify conformance to the requirements with a system of practical size.

3.5.3 General Design Requirements

3.5.3.1 General

The TCS shall meet the applicable requirements of MSCM 8080.

APPENDIX B
EXPENDABLE WATER HEAT REJECTION SUBSYSTEMS
THEORY OF OPERATION

APPENDIX B

EXPENDABLE WATER HEAT REJECTION SUBSYSTEMS

THEORY OF OPERATION

B1.0 INTRODUCTION

In order to successfully develop a thermal control subsystem for a Shuttle Extravehicular Life Support System (EVLSS) application, total understanding of the theory of operation of the candidate heat rejection subsystems (HRS) is required. A comprehensive understanding of the theory of operation ensures that problem areas are properly identified and a sound technical approach to overcome these problem areas are developed.

This appendix discusses the theory of operation for the water boiler, water sublimator and the flash evaporator.

B2.0 WICK FED WATER BOILER

The wick fed water boiler is an expendable thermal control concept that utilizes the heat of vaporization of water stored in the wick to provide direct cooling of the Liquid Cooling Garment (LCG) loop and vent loop. Water is transported to the metal boiling surface by a wicking material, which also acts as the storage medium for the expendable water. Downstream of the metal boiling surface, a vapor exhaust passage is vented to vacuum ambient which causes a reduction in pressure at the metal boiling surface. This reduction in pressure causes water at the metal boiling surface to evaporate.

The available heat sink for water boiling operation depends on the rate that water can be wicked to the metal boiling surface and on the heat of vaporization at the evaporant temperature of the metal boiling surface. The evaporant temperature is governed by the pressure at the metal boiling surface. This pressure is controlled by a back pressure valve, which may be either temperature sensing or pressure sensing. Based on the evaporant temperature, the overall performance of the water boiler can then be determined by an analysis of the conductive heat transfer path from the metal boiling surface to the LCG water.

B2.1 Design Criteria

In the design of a wick fed water boiler, the factors tabulated in table B2-1 must be considered. The wicking material must be analyzed for compressibility, water retention characteristics, water transport capability, and open volume. The metal boiling surface wetting properties must be known, and the percentage of plate open area and its effect on overall unit performance must be determined. The back pressure control scheme and its effect on evaporant temperature and the overall area available for heat transfer must also be calculated to properly define total heat exchanger performance. The final size of the unit will then depend on the required heat transfer or wicking surface area, the amount of water that the wicking material is required to store, and the physical properties of the wicking material.

The wicking device is used both as the water storage and transport medium to the boiling plate surface. Water flow is caused by the wick density driving force; i.e., the small capillaries pull water from the larger capillaries. A wick with uniform capillary diameters will not induce flow. These facts were corroborated by test during the design of the NASA ARC Ice Pack Heat Sink Subsystem depicted pictorially in figure B2-1.

As represented by figure B2-1a, a wet wick is held against a hot surface and compressed to produce small capillaries at the hot end. In this case, water vapor could be observed forming at the hot end. Figure B2-1b depicts the case where a wet wick is held against a hot surface and compressed at the end of the wick away from the hot surface. In this case, no water vapor was observed, and the wick began to burn at the hot end. These rather simple tests dramatically demonstrated both the wick density driving force and the need for the wick to be compressed in a controlled manner, at the metal boiling surface, to ensure water flow to the boiling surface.

A) COMPRESSED AT HOT END

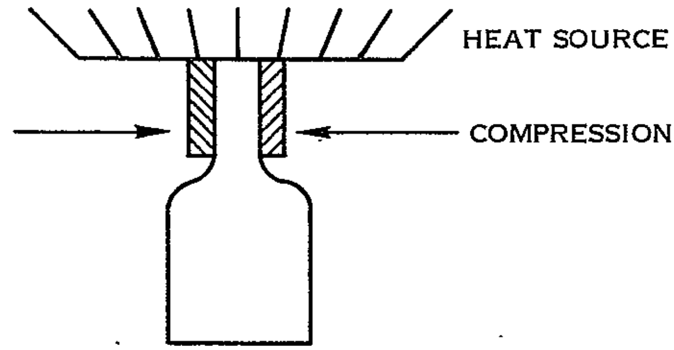


FIGURE B2-1A. WICKING MECHANICS

B) COMPRESSED AT COLD END

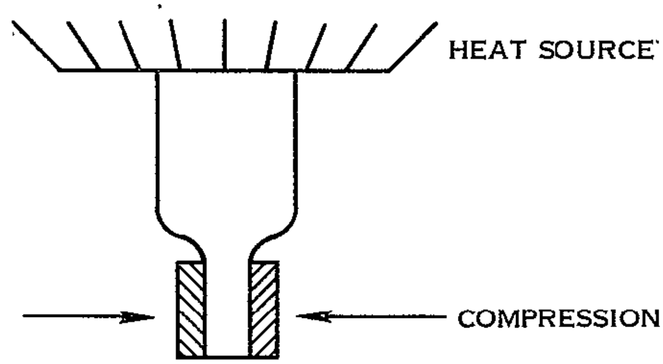


FIGURE B2-1B. WICKING MECHANICS

B2.1 (Continued)

TABLE B2-1

WICK FED WATER BOILER DESIGN CRITERIA

Major Area	Factors to be Considered
Wicking Material	• Compressibility • Water Retention Characteristics • Water Transport Capability • Open Volume
Boiling Surface	• Wetting Properties • Open Area
Back Pressure Control	Effect on Evaporant Temperature
Performance	Heat Transfer Area
Wicking Volume	• Heat Transfer Area • Wicking Surface Area • Total Water Storage • Wick Properties

Contact must always be maintained with the metal boiling surface. If, for any reason, the wick loses contact with the boiling surface, the vapor pressure drop will increase due to the increased flow path. This inturn will increase the evaporation (sink) temperature, thus reducing the unit's cooling capacity.

Along with the need for the wick to be compressible to ensure water transport, several other factors must also be considered. One of these is the capillary wicking head, which is the height of water that a wick can draw when placed vertically with one end in a liquid supply. A wick with sufficient capillary wicking head will provide for proper water retention in the water boiler when in a 1-g environment.

This precludes water dripping into the vapor passages where the possibility of freezing exists when the passage is vented to vacuum.

Another criterion is that the wick have high porosity. Porosity is defined as the wick void volume divided by the wick total volume. A wick of high porosity will provide for a smaller water boiler size than one with low porosity.

Table B2-2 presents candidate wicking materials and comments on each. From this information, Dacron #67DA 18/0.068 was chosen for its compressibility, capillary wicking head, and porosity characteristics.

A model cell for a previous application was made of plexiglas, filled with wicking material, expansion foam and water, and hot air was blown over it. The purpose was to ascertain, whether, for the range of conditions in which the subsystem was to be used, the wick can transport enough water to satisfy the heat load requirements.

TABLE B2-2
CANDIDATE WICKING MATERIALS

Material	Description	Manufacturer	Porosity $\left(\frac{\text{Void Vol.}}{\text{Total Vol.}}\right)$	Wicking Capillary Head (in. H_2O)	Comments
Rayon	#432 Woven Synthetic	Troy Felt	0.580	0.875	Insufficient Capillary Head
	#182	Troy Felt	0.748	0.875	Insufficient Capillary Head
Dacron	#S4-0.070	Troy Felt	0.481	4.25	Insufficient Porosity
	#S4-0.125	Troy Felt	0.525	4.63	Insufficient Porosity
	#62DA 11/125	American Felt	0.937	1.50	Insufficient Capillary Head
	#67DA 18/0.068	American Felt	0.835	5	Good
Orlon	#2B-9	Troy Felt	0.920	0.5	Insufficient Capillary Head
Polypropylene	#342-1000	Troy Felt	0.774	3.0	Insufficient Porosity
	#342	Troy Felt	0.742	2.25	Insufficient Porosity and Capillary Wicking Head
Nylon Felt	452-24-344	Various	0.513	1.1	Insufficient Porosity and Capillary Wicking Head
Rafrasil Cloth	C100-96	Hitco	0.580	> 10	Insufficient Porosity

B2.1 (Continued)

The heat sink available in any evaporating mechanism is dependent on the amount of mass evaporated and the heat of vaporization at the evaporant temperature. Any wicking device is flow limited at some maximum flow due to surface tension within the capillaries. Furthermore, there will always be some water retained in the wick which can not be drawn out due to surface tension effects. A test was run to determine the water transport and retention characteristics of the Dacron S4 materials, which exhibit characteristics similar to Dacron 67DA material which was unavailable at the time of this test. Results are presented in Figure B2-2. The model cell was run on a weight scale with readings taken over specified time intervals to determine the amount of water evaporating. Temperature measurements were taken by a thermocouple at the cell model evaporating surface. The results indicate that for this type of application, the wick can pass sufficient water flow to satisfy all heat loads required if a proper wicking surface area is provided (approximately 151 in^2 for 3100 Btu/hr). The results also indicate that 80% of the water in the module can be wicked to the boiling surface before the wick will no longer pass water due to the emptying of the large capillaries.

The metal boiling surface is designed to provide a proper medium for water boiling. High wicking capillary head will eliminate metal boiling surface water retention as a design criteria. The material of the metal boiling surface should be similar to that in the rest of the water boiler providing for ease of manufacture and assembly. The range of open area should be picked to maintain high thermal conductivity through the metal boiling surface. Since any bare metal is a wetting surface, the metal boiling surface is assumed to be hydrophilic; i.e., the water is retained on the metal boiling surface at the downstream end of the open area. This assumption eliminates the need for pressure drop calculations across the metal boiling surface to determine evaporant temperature. Furthermore, the boiling surface conductivity can then be calculated by treating the conductive heat transfer path as a parallel arrangement of aluminum and water. (See Figure B2-3.) Therefore,

$$K_{eff} = \left(1 - P\right) K_m + P K_L \qquad (1)$$

where K_{eff} is the thermal conductivity of the parallel aluminum/water arrangement, K_m is the thermal conductivity of the metal, K_L is the thermal conductivity of water, and P is the fraction of plate open area divided by the plate total area. By holding the area fraction P to a minimum, the effective thermal conductivity K_{eff} is held high, since $K_m \gg K_L$. For any given heat load Q, the temperature drop, ΔT, can be held to a minimum since

$$Q = \frac{K_{eff} A}{x} \Delta T \qquad (2)$$

where A is the cross-sectional area of the heat transfer path and x is the length of the path.

The back pressure valve is designed to control the pressure at the metal boiling surface.

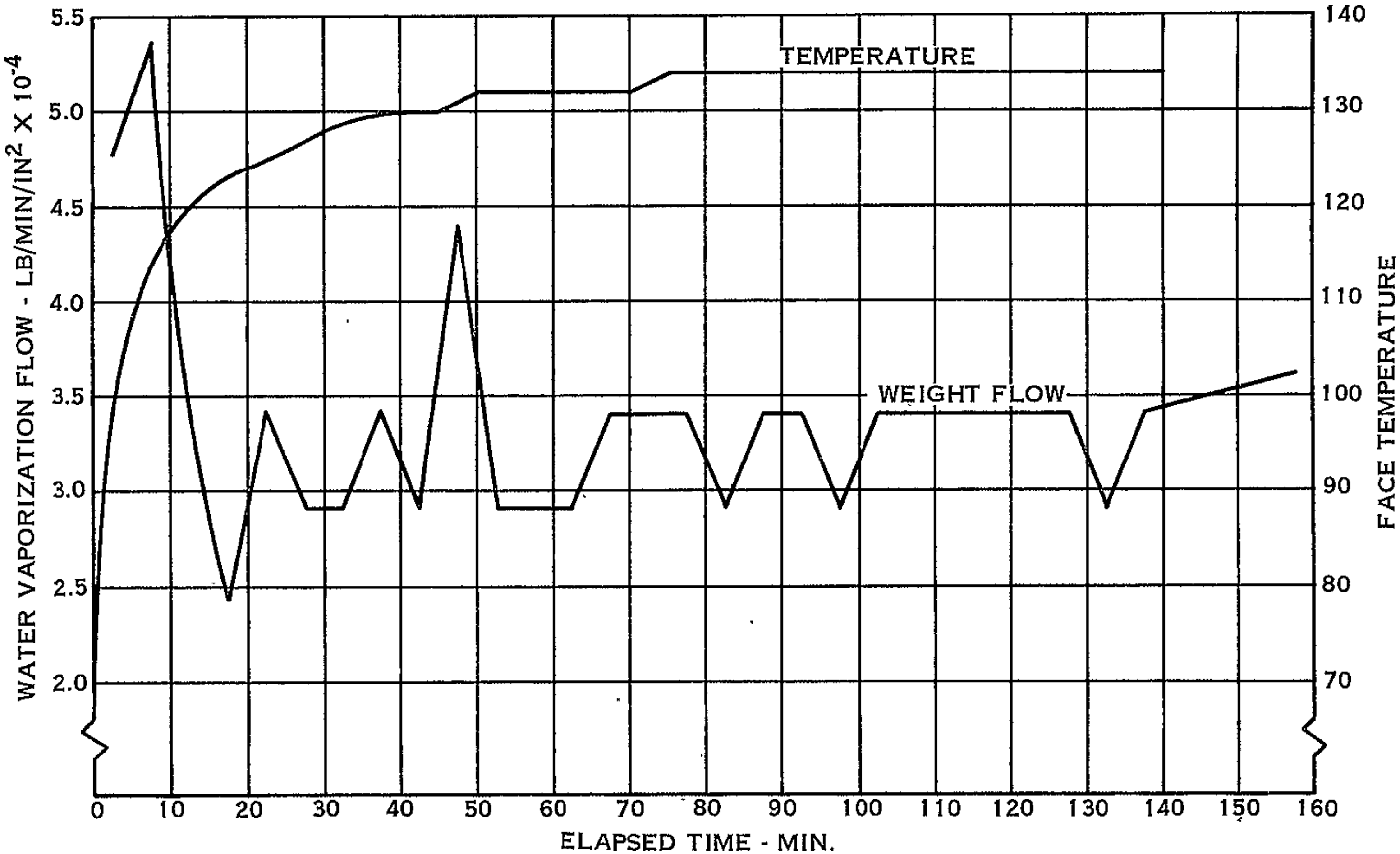
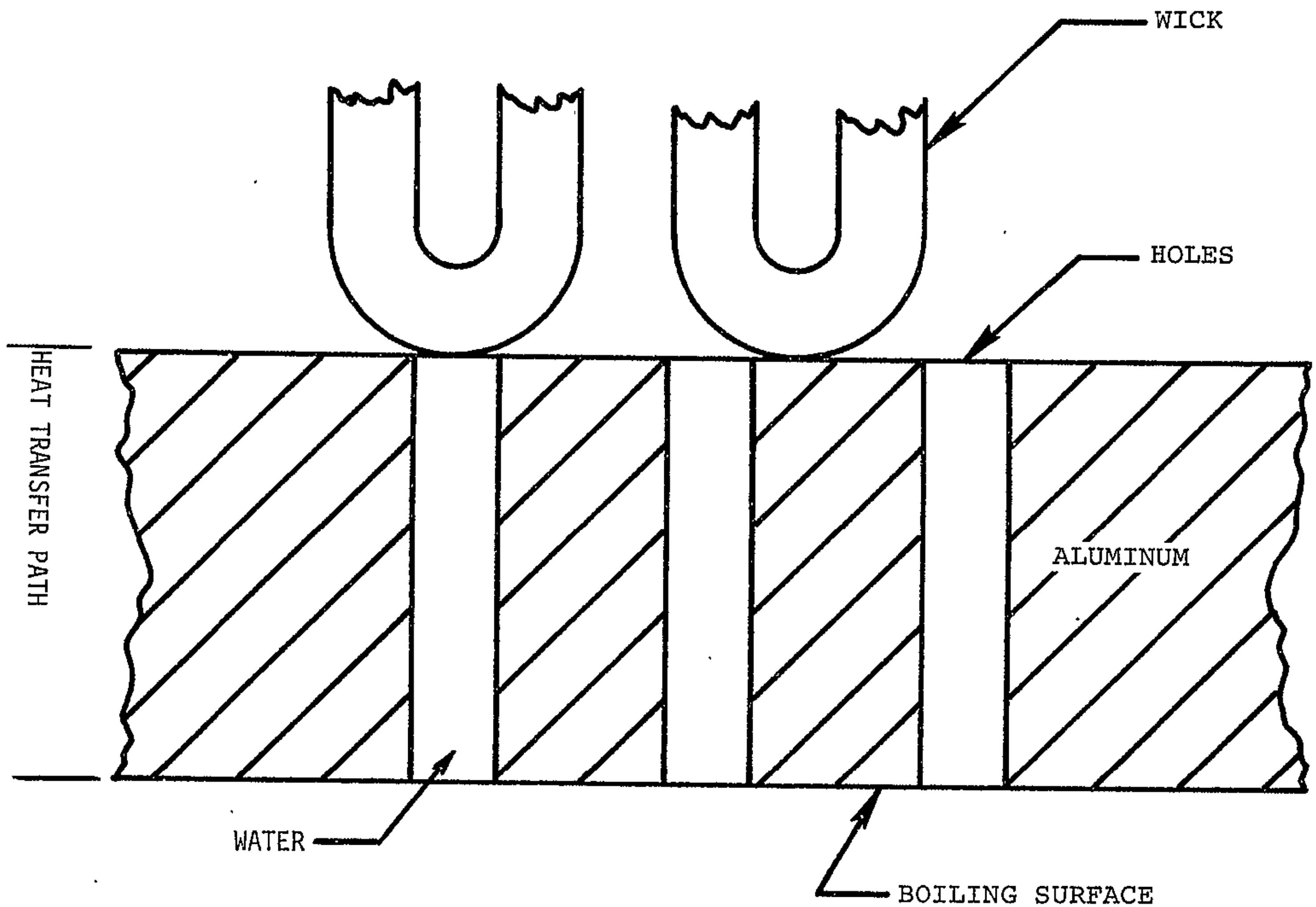


FIGURE B2—2. DACRON WICKING TEST



PARALLEL HEAT TRANSFER PATH

FIGURE B2-3

B2.1 (Continued)

This pressure then determines the evaporant temperature at the metal boiling surface and limits the amount of water vapor that can be vented overboard. This combination of evaporant temperature and water vapor flow then determines the amount of heat that can be removed from the system.

Water boiler performance is calculated by an analysis of the conductive path from the LCG cooling water to the boiling vapor. The total temperature drop along the conductive path is used to calculate an overall conductance, UA, by use of the relationship.

$$\frac{1}{UA} = \frac{\Delta T}{q} \tag{3}$$

where q is the heat transfer rate and ΔT is the total temperature drop from the LCG cooling water wall to the evaporant surface. Over the range of heat loads being considered, the overall conductance UA is assumed to be a constant.

Once the required heat transfer area and required wicking surface area has been calculated, the final size of the wicking volume can be determined based on the larger of the two surface area requirements. The mass of water required is defined by

$$M_{H_2O} \doteq Q/h_{fg} \tag{4}$$

where Q is the total mission heat load and h_{fg} is the heat of vaporization. The total required storage volume can then be calculated by

$$V = M_{H_2O} / \left(\rho H_2O \times P_W \times E_W \right) \tag{5}$$

where

V ~ total storage volume

ρH_2O ~ density of water

P_W ~ porosity of the wicking material

E_W ~ fraction of water stored in the wick that can be transported to the metal boiling surface (0.8)

Knowing the maximum of the heat transfer area or wicking surface area requirement, the height of the wicking material can be calculated.

B2.2 Conclusions

A water boiler used for emergency mode operation for the NASA ARS Ice Pack Heat Sink Subsystem has recently completed development testing at Hamilton Standard. This specific unit has no back pressure valve or feedwater loop and has a contact resistance between the metal boiling surface and LCG water loop. The vapor passage was vented overboard through an orifice and only water that had been previously stored in the unit was available for evaporation. Even with this added limitation on pressure drop due to the fixed orifice size and increased conductive temperature drop due to the contact, the unit successfully handled cooling loads of 139-880 watts (475-3000 BTU/hr) while providing satisfactory LCG outlet temperatures.

It is therefore concluded that the wick fed water boiler concept can meet the required heat loads, and, with the addition of the back pressure control scheme, can provide satisfactory LCG and vent loop outlet temperatures.

B2.3 References

a. Chi, S. W.; Introduction to Heat Pipe Theory: An Instruction Manual; The George Washington University; October 1971.

b. Kunz, H. R.; Langston, L. S.; Hilton, B. H.; Wycle, S. S.; and Nashick, G. H.; Vapor Chamber Fin Studies: Transport Properties and Boiling Characteristics of Wicks; Pratt & Whitney Aircraft, NASA Contract Report NASA CR-812; June 1967.

c. Sangiovanni, J. J. and Hepner, P. H.; Porous Plate Water Boiler Design Study Final Report; Hamilton Standard Report HSER 3509; May 20, 1965.

d. First Quarterly Progress Report, Ice Pack Heat Sink Subsystem ECS-2124-L-015, Contract NAS 2-7011, September, 1972.

B3.0 FLASH EVAPORATOR

The flash evaporator is an expendable thermal control concept that utilizes the heat of vaporization of water to provide direct cooling of the LCG and vent loops. Water is sprayed on the metal heat exchange surface by a nozzle which forms a hollow cone spray pattern. The amount of water sprayed on the heat exchange surface is controlled by supply rate pulse modulation. The metal heat exchange surface is finned to provide more effective area for heat transfer and is surrounded by a chamber that is vented to a vacuum ambient. This causes a reduction in pressure at the heat exchange surface which forces the water sprayed on the heat exchange surface to evaporate. The pressure that exists in the chamber is governed by proper sizing of the vent area between the chamber and the vacuum ambient.

The spraying flash evaporator effectively utilizes the heat of vaporization of expendable water with little or no wasted water (carryover). No performance degradation is experienced due to corrosion or blockage of the boiling surface and no loss of unit effectiveness can occur by loss of contact between the heat exchange surface and the expendable water transport medium. However, the unit requires a fairly complex control scheme to provide the expendable water supply rate pulse modulation needed to control cooling. The nozzle design is also crucial to produce the proper expendable water spray pattern.

B3.1 Design Criteria

In the design of a flash evaporator, the following factors tabulated in table B.3-1 must be considered. The configuration of the heat exchange surface must be analyzed for the most optimum use of uneven spray patterns that exist in hollow cone spray nozzles. The proper configuration of the heat exchange surface in combination with the spray nozzle will minimize possible liquid accumulation problems on the heat exchange surface. This accumulation can be liquid or solid depending on whether the chamber pressure is above or below the triple point pressure. The vent area between the chamber and vacuum ambient must be sized to prevent liquid freezing in transit between the nozzle and heat exchange surface, while maintaining pressure levels in the chamber that provide good evaporant (sink) temperatures. Finally, the optimum location for the controller sensor must be determined and controller supply rate pulse time must be calculated.

When the expendable water is sprayed on the heat exchange surface, several conditions may exist. If pressure in the chamber is too low, the water droplets could freeze in transit and bounce off the heat exchange surface, thus reducing unit efficiency because of the inability of the water to evaporate. If the particles do not freeze in transit, one of the several boiling regimes is present. These boiling regimes are depicted in figure B3-1. The droplets could impinge on the wall and evaporate. In droplet evaporation (Regime I), evaporation will occur at the free liquid surface. The droplet could also impinge on the wall and evaporate gently (Regimes II and III). In this form of evaporation, called nucleate boiling, vapor bubbles form at the hot surface and rise to the free

TABLE B.3-1
SPRAYING FLASH EVAPORATOR DESIGN CRITERIA

Major Areas	Factors to be Considered
Heat Transfer Mechanism	Operational Limits
Heat Exchange Surface	• Spray Pattern • Spray Pattern Utilization • Unit Envelope
Vent Area	• Chamber Pressure • Chamber Evaporant Temperature • Operational Limits
Control Scheme	• Sensor Location • Supply Pulse Time • Start-up Time Lag

B 3.1 (Continued)

liquid surface. Both droplet evaporation and nucleate boiling will produce efficient evaporation. If the input heat flux becomes very large, an unstable film forms on the hot heat exchange surface from which large bubbles will form and collapse. This is the transition boiling regime and is depicted by regime IV. The unstable film on the hot heat exchange surface provides additional resistance to heat transfer with a resultant decrease in the heat transfer rate and increase in the heat exchange surface temperature. Spray rebound in the violent boiling mode also reduces unit effectiveness due to loss of liquid. Finally, if the expendable liquid is applied to the heat exchange surface much faster than evaporation occurs, the water will accumulate and freeze on the heat exchange surface thereby reducing unit efficiency in the same manner that the unstable film of transition boiling does. The unit must thus be designed for either droplet evaporation or nucleate boiling operation, avoiding the extremes of droplets freezing in transit and liquid film build-ups on the heat exchange surface.

For the Shuttle EVLSS application, the coolant water outlet temperature is to be 7.22°C (45°F). For the maximum heat load requirement and the heat exchange properties of the designed unit, the wall temperature would be approximately 1.1 °C (34°F). Reasonable evaporation (sink) temperatures are on the order of -2.2 to 0°C (28-32 °F). The temperature differential between the wall and the sink (i.e., $T_W - T_{sat}$) thus ranges

B3.1 (Continued)

Ref: Rohsenow and Choi; Heat, Mass, and Momentum Transfer

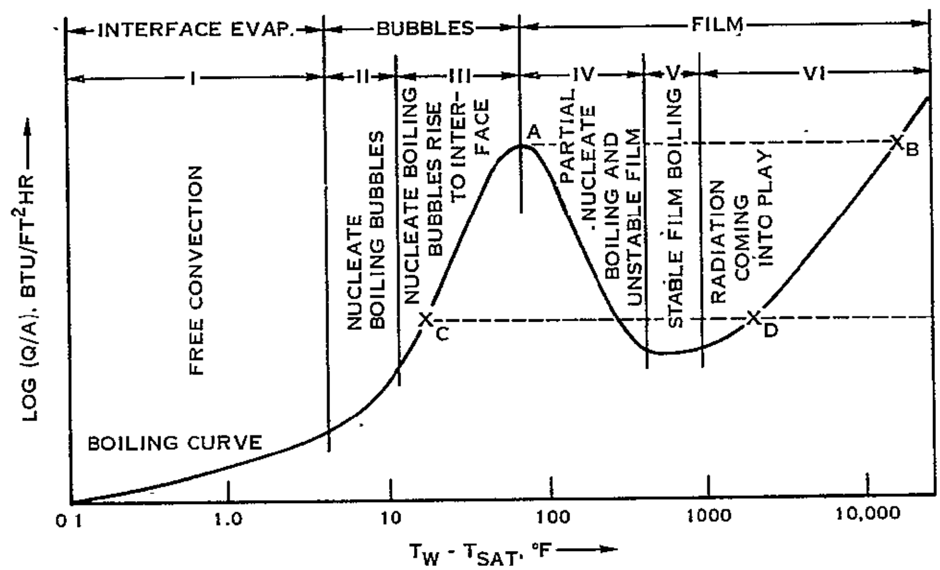


FIGURE B3-1. BOILING REGIMES

from 1.11-3.33°C (2-6°F). Referring to Figure B3-1, it can be seen that this temperature differential occurs in Regimes I and II, resulting in either droplet evaporation or nucleate boiling as the modes of operation of the spraying flash evaporator.

Both flat plate and grooved cylinder type heat exchange surfaces have recently been tested at Hamilton Standard as part of IR D effort. It has been determined that the cylindrical form provides more effective utilizationof the hollow cone spray pattern. The overall envelope of the cylindrical unit will be smaller than the flat plate unit for several reasons. One is that the flat plate unit must be at a greater distance from the nozzle to obtain the needed heat transfer area than the cylindrical unit. Furthermore, the flat plate unit will have more unused area due to the hollow cone spray pattern than the cylindrical unit. Finally, to effectively match the hollow cone spray pattern, the flat plate heat exchanger would have to be rounded, instead of having rectangular dimensions.

Along with reducing the overall envelope of the unit, the cylindrical heat exchange surface yields more effective heat transfer because of a more effective utilization of uneven spray patterns. The heat exchange surface is most effective with uniform fluid-to-wall temperature differentials. If the temperature differential is larger in certain areas, then those areas would have lower surface temperatures, thus controlling the evaporative flux that could be maintained before liquid accumulated on the heat exchange surface. The cylindrical heat exchange surface provides for a more uniform spray pattern utilization when combined with LCG film coefficients and, therefore, provides a more uniform temperature differential on the surface. The heat exchange surface is also finned to provide more effective area for heat transfer.

B3.1 (Continued)

As presently designed, the coolant water passes through a cylindrical grooved heat exchanger sized for the desired temperature and pressure drops. The coolant water passes through eight parallel grooves which are machined into the surface by a standard screw thread machining process. The coolant water passage sizing is based on heat transfer properties at the heat exchanger outlet and on a logarithmic temperature difference based on heat exchanger inlet and outlet temperatures and on the evaporation (sink) temperature.

The log mean temperature difference is required because the expendable liquid spray mass flux is non-linear over the heat exchange surface.

The hollow cone spray nozzle is designed for a more uniform temperature distribution on the wall thus minimizing possible liquid accumulation problems. One difficulty which frequently arises from spraying flash evaporators is the freezing of the nozzle during the off-time of the supply rate pulse modulation. This problem of ice formation in the nozzle is minimized by limiting the nozzle liquid dribble volume to a mass that is not able to reduce the thermal mass of the nozzle itself below the freezing temperature. This is accomplished by locating the shut-off valve as close to the nozzle outlet as possible.

The vent area in the bottom plate of the cylinder (figure B 3-2) determines the chamber pressure, and thus the evaporation temperature, while the nozzle is spraying. If the vent area is too large, the chamber pressure is lowered to the point where the liquid droplets can freeze in transit from the nozzle to the heat exchanger surface. Tests recently run at Hamilton Standard with the cylindrical end plate removed corroborated this theory. The removal of the end plate increased liquid carryover (that portion of the spraying water which is not available for heat transfer) substantially over the carryover experienced with the end plate attached, since water droplets were freezing in transit and were unavailable for heat transfer. At the other end of the spectrum is the case where the vent area is too small. This will result in an increase in the chamber pressure with a subsequent increase of the evaporation (sink) temperature, thus causing a rise in the heat exchanger outlet temperature. The designed vent area must then be large enough to provide proper sink temperatures under maximum heat loads and maximum expendable water mass flux. It must also be small enough so that the expendable liquid droplets will not freeze in transit under conditions of minimum heat load and minimum expendable liquid flux.

Once an acceptable vent area has been determined, another factor must also be considered. If the vent area is opened up even more, it may be possible to lower the evaporation (sink) temperature by lowering chamber pressure. However, it is also possible that the liquid droplets on the heat exchange surface will freeze when chamber pressure is at or below triple point pressure, thus limiting the sink temperature to a minimum of

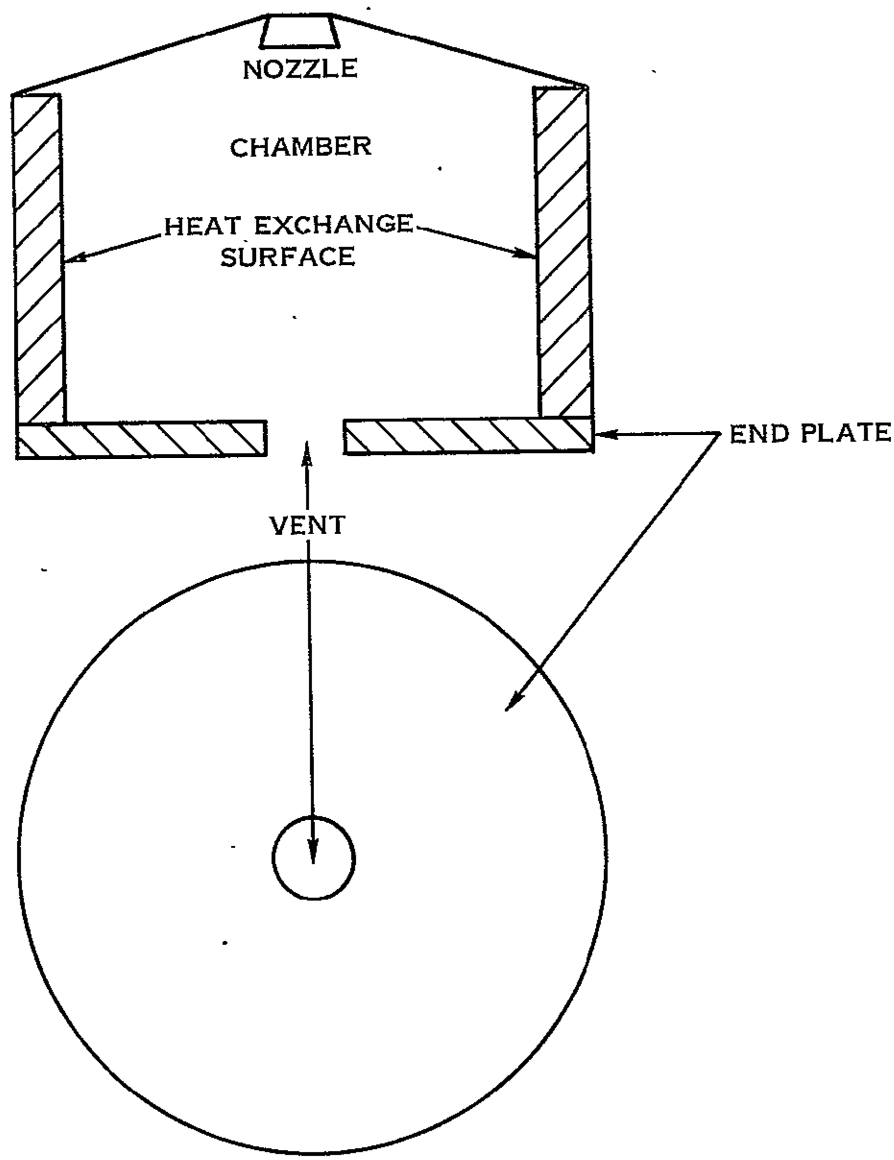


FIGURE B3–2. GENERAL CHAMBER CONFIGURATION

B3.1 (Continued)

0°C (32°F). The sensitivity of the chamber and evaporation conditions to the vent area must be determined empirically to judge the feasibility of vent area increases.

Analytically, the governing equations, assuming a dump to ambient conditions, are:

1. $T_c = f(Pc)$
2. $V = \dot{W}/A_{vent}\,(\rho c)$
3. $P_c = Pa + \dfrac{\rho c V^2}{2g}$

where

W ~ weight flow

P ~ pressure

T ~ temperature

V ~ velocity

A ~ area

ρ ~ density

g ~ gravitational constant and

subscripts a ~ ambient

c ~ chamber

vent ~ vent

The controller/sensor is designed to provide supply rate pulse modulation. The sensor is immersed in the coolant outlet line as this method is not susceptible to inaccuracies under varying heat loads, such as might develop when sensing wall temperatures. Under a wall temperature sensing scheme, the temperature differential between coolant outlet temperature and wall temperature will change under varying heat loads.

The controller provides a constant time nozzle on pulse, with the length of the on-time pulse proportional to the thermal loads. It is desirable to maintain a maximum on-time, so as to minimize the total number of cycles required, thus increasing the life of the unit. The on-time can be optimized based on the coolant outlet temperature band desired, i.e., the larger the temperature band, the larger the on-time required. The governing equations for the pulse are:

$$\dot{q}_{vapor} = (To - To')\,(\dot{m}_{HX}\,Cp_{HX} + \dot{m}_{H_2O}\,Cp_{H_2O}) + \dot{W}_{H_2O}\,Cp_{H_2O}\,(T_{in} - T_o')\,\Delta\tau \quad (4)$$

$$\dot{q}_{vapor} = \dot{W}_{nozzle}\,h_{fg}\,\Delta\tau \quad (5)$$

B3.1 (Continued)

where

$\dot{q}$ ~ heat flux

T ~ temperature

$\dot{m}$ ~ mass

C_p ~ specific heat

$\dot{W}$ ~ weight flow

h_{fg} ~ heat of vaporization

τ ~ time

and the subscripts are referred as follows:

vapor ~ evaporation mechanism

nozzle ~ nozzle

O coolant outlet, upper value of controller temperature band

O' coolant outlet, lower value of controller temperature band

HX heat exchanger

H_2O coolant water

in heat exchanger inlet

Therefore, for a given controller temperature band, the on-time of the nozzle spray can be calculated directly by the above procedure. However, the lag time for the cooled liquid slug in the heat exchanger to reach the temperature sensor must also be considered. Under start-up conditions with low heat loads and low coolant flow rates, it is possible to freeze up the unit before the cooled water slug reaches the temperature sensor. This problem can be alleviated either by designing controller features to account for the water slug time lag during start-up or by placing the temperature sensor close to the heat exchanger outlet to reduce the time lag.

B3.2 References

1. Gaddis, J. L.; The Flash Evaporator for Transient Heat Loads; presented at the Joint AIAA/NASA Space Shuttle Technology Conference; Phoenix, Arizona, March 18, 1971.

2. Gaddis, J. L.; Development of a Laboratory Prototype Spraying Flash Evaporator; Aviation & Space Division of the American Society of Mechanical Engineers for presentation at the Environmental Control and Life Support Systems Conference; San Francisco, California, Aug. 14-16, 1972.

3. Choi, H. and Rohsenow, W. M.; Heat, Mass, and Momentum Transfer, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1961.

B4.0 SUBLIMATOR - APOLLO TYPE

The porous plate sublimator utilizes sublimation/boiling mechanisms to provide the LCG and ventilation loop cooling. The actual mechanism being utilized at any given time is a function of the porous plate characteristics and the applied heat load.

The sublimator is self-regulating by variations in the ice layer in the sublimating mode and by vapor pressure drop in the evaporating mode up to the point where liquid breakthrough occurs. The liquid breakthrough is caused by the inability of the porous plate to sustain pressure differentials above a given maximum. However, until the point where liquid breakthrough occurs, there is no loss of unit efficiency due to carry-over.

B4.1 Design Criteria

The various mechanisms by which cooling is accomplished (sublimation, evaporation) are discussed in detail below. For design purposes, the average sink temperature can be assumed to be at the freezing point temperature of 0°C (32°F) until liquid breakthrough occurs. All empirical data is then related to this sink temperature to determine the effectiveness of comparable units.

Further design criteria involve the porous plate properties. Sufficient porous plate water retention properties must be assured to prevent liquid breakthrough over the range of heat loads and pressure differentials that will be encountered. As the necessary water retaining force is supplied by surface tension, which is inversely proportional to the equivalent radius of the pore, hole size can be critical depending on the pressure differential the unit will see. It is also desirable to determine the porous plate wettability characteristics, as this will affect the actual cooling mechanism that occurs as discussed below.

The flow distribution in the liquid gap may also affect the heat load that the sublimator can handle. If the unit becomes flow limited at a given water feed pressure, proper cooling may not be obtained. In the design of a water sublimator, the factors listed in table B4-1 must be considered.

TABLE B4-1
SUBLIMATOR DESIGN CRITERIA

Major Area	Factors to be Considered
Cooling Mechanism	• Sublimation • Evaporation
Porous Plate	• Water Retention Properties • Hole Size • Pressure Differential • Wettability
Feedwater	Flow Distribution

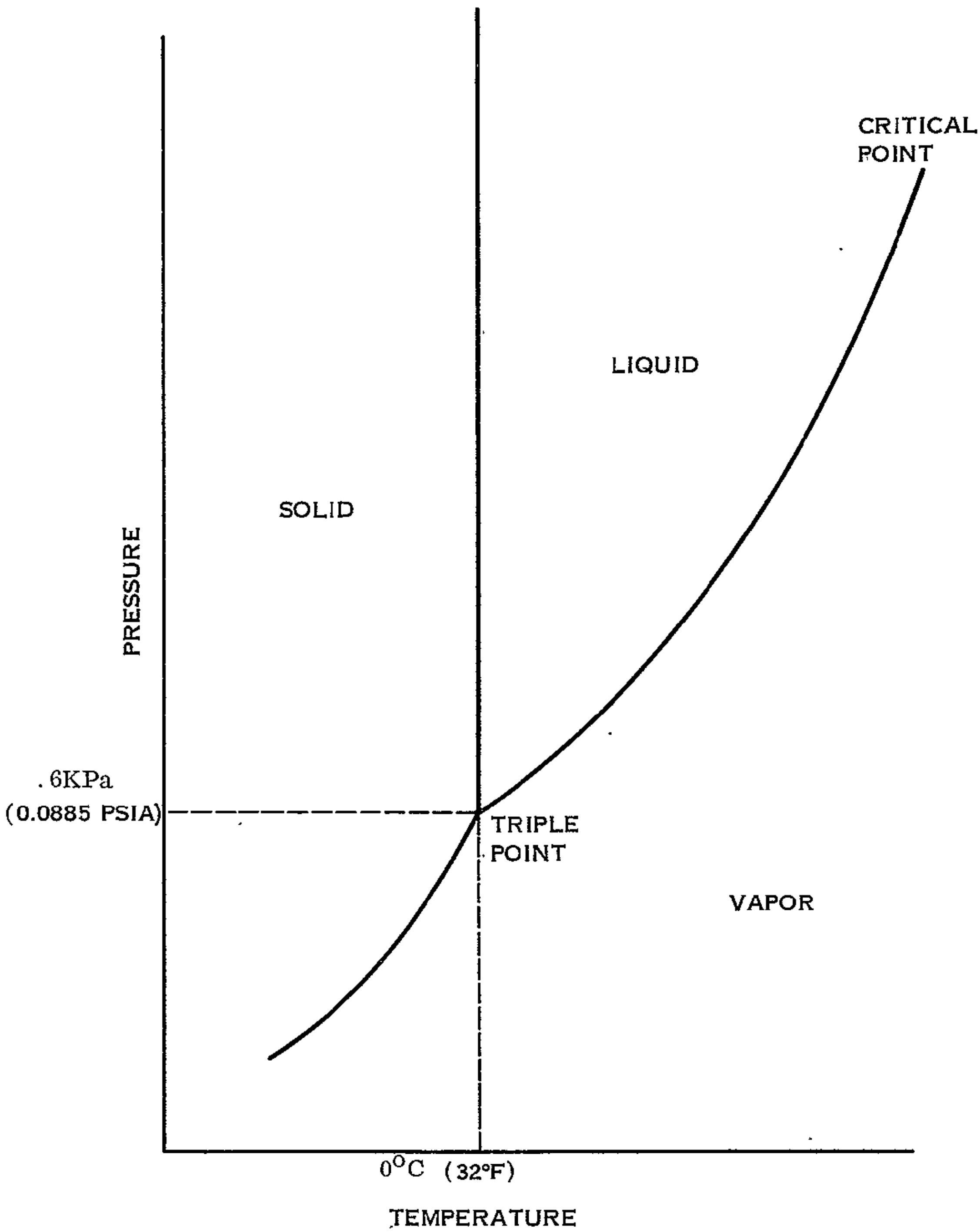


FIGURE B4–1. EQUILIBRIUM PHASE DIAGRAM FOR WATER

B4.1 (Continued)

The sublimation mechanism is characterized by a layer of ice on the inside face of the porous plate, which prevents liquid from passing into the plate and escaping to the ambient. The existence of this ice layer is determined by a combination of the vapor pressure drop characteristics of the porous plate and the heat flux of vapor flow rate. When the vapor pressure drop of the porous plate is less than the triple point pressure indicated by the equilibrium diagram for the expendable substance (figure B4-1), the phase change must be from the solid directly to the vapor phase, by sublimation of the ice layer. The thickness of the ice is governed by the rate of heat transfer and the sublimation temperature corresponding to the local vapor pressure at the inlet face of the porous plate. For this mode, the sublimation (sink) temperature is less than the freezing temperature. It can be shown that normal operating pressure differentials across the porous plate and ice layer are insufficient to extrude the ice into the pores and thus the ice forms a barrier to liquid flow into the pores. However, based on the vapor pressure drop of the porous plate and the applied heat load, the ice layer could exist within the pores with liquid on the upstream face of the plate. In order to accommodate the heat transfer requirement, the ice sublimates at the porous plate face and freezes at a corresponding rate at the liquid interface. The ice, therefore, flows somewhat in the manner of a glacier toward the porous plate, but at an extremely slow rate while serving as a heat conduction media. This was actually observed by following small gas inclusions in the ice during visual tests of operating modules conducted at Hamilton Standard.

Based on kinetic theory, utilizing equation 1, the mean free molecular path for water vapor at triple point conditions, λ, can be calculated as 6.95×10^{-6} meters.

$$\lambda = \frac{\mu}{P}\sqrt{\frac{\pi R T}{2 g_o}} \qquad (1)$$

$\mu \sim$ dynamic viscosity

$P \sim$ pressure

$T \sim$ temperature

$R \sim$ gas constant

$g_o \sim$ gravitational constant

Since the range of diameters in the porous plate will be from 2 to 15 microns, which is smaller than the calculated mean free molecular path, the flow may be categorized as free molecular.

Again employing kinetic theory analysis, the Knudsen equation for free molecular flow in a capillary (equation 2) can be used to relate the pressure at the sublimation interface to the ambient pressure.

B4.1 (Continued)

$$\Delta P = P - P_a = \frac{6\,\dot{m}\,t}{D^3}\sqrt{\frac{RT}{2\,\pi\,g_o}} \qquad (2)$$

where $P \sim$ pressure

$T \sim$ temperature

$\dot{m} \sim$ pore mass flow rate

$D \sim$ pore diameter

$t \sim$ porous plate thickness

$R \sim$ gas constant

$g_o \sim$ gravitational constant

and subscript a denotes ambient conditions.

Referring to figure B4-2, the heat transfer across the liquid and ice layers can be expressed as

$$q_1/A = q_o/A = (K_1\,/L)\,(T_o-32) \text{ and } q_2/A = (k_i/I)\,(32-T_s) \qquad (3)$$

where k is the effective thermal conductivity of the respective layers. The boundary conditions of the ice layer are:

$$q_2/A = q_1/A + W/A\;\; h_f \qquad (4)$$

at the liquid interface, and

$$q_2/A = W/A\; h_s \qquad (5)$$

at the sublimating face, where h_f and h_s are the heats of fusion and sublimation, respectively.

By combining these expressions algebraically, the temperature of the heated surface can be written as:

$$T_o = 32 + 1/k_1\left[q_o/A \;\cdot\; \delta - k_i\,(1-\frac{h_f}{h_s}\;)\;\cdot\;(32-T_s)\right] \qquad (6)$$

where T_s is the sublimation temperature and is related to the local pressure for solid-vapor equilibrium.

The ice layer thickness can also be derived from the above expressions, giving

$$I = \frac{k_i\,(32-T_s)\;\cdot\;(h_s-h_f)}{q_o/A\;\cdot\;h_s} \qquad (7)$$

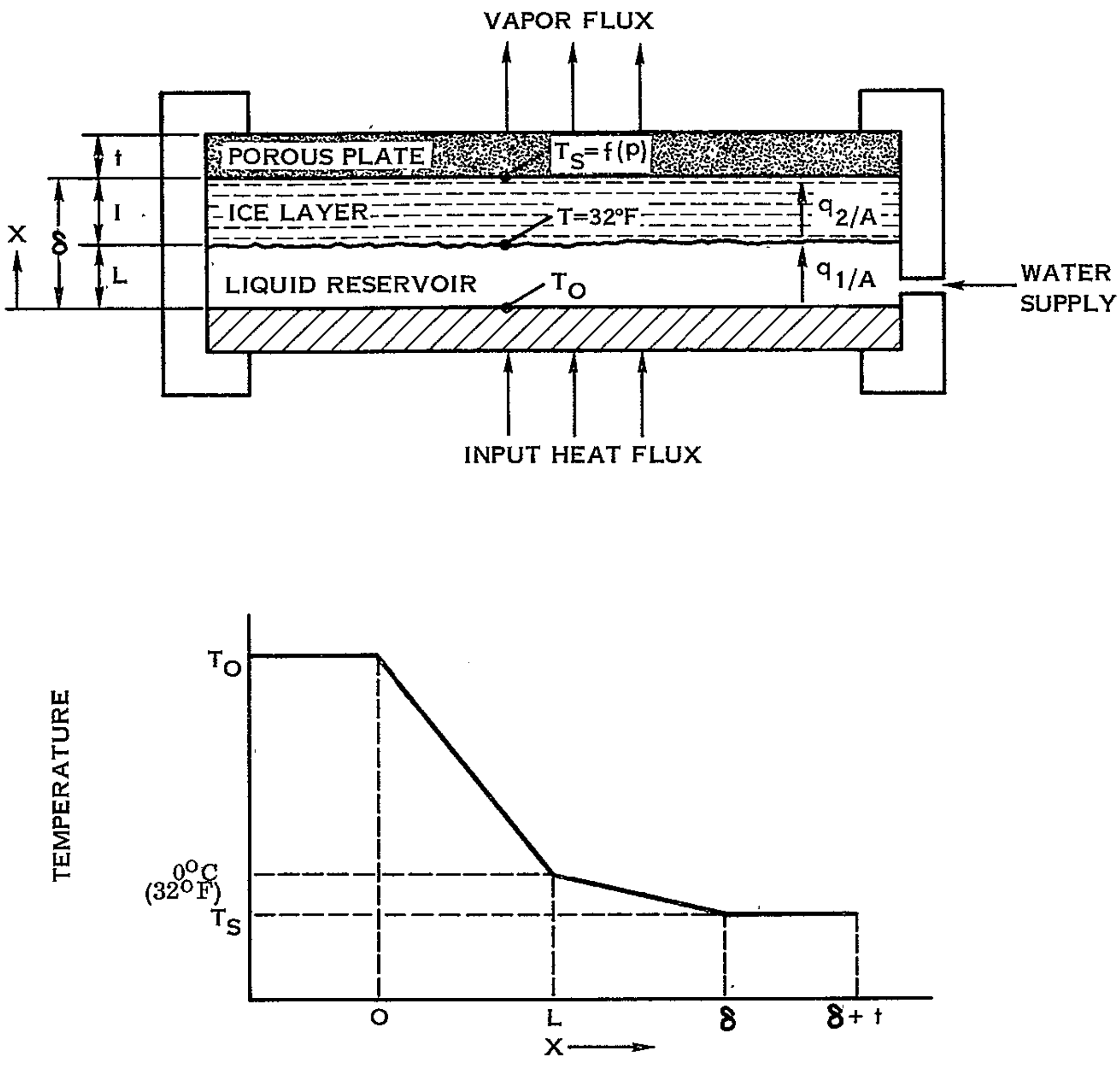


FIGURE B4-2. MODEL FOR ANALSIS OF SUBLIMATION MECHANISM

B4.1 (Continued)

If the input heat flux is increased, the vapor pressure drop across the porous plate increases causing the sublimation temperature to rise accordingly. This results in a reduction in the ice layer thickness in order to satisfy the heat conduction requirements. Eventually the ice layer will disappear completely when the heat flux is sufficient to cause the vapor pressure at the inlet face of the porous plate to be greater than the triple point pressure. It is at this point that the evaporation mechanism begins to occur. However, if the pore size distribution is non-uniform, the heat flux at which this transition occurs will vary with location on the plate due to inequalities in vapor pressure drop, resulting in mixed mode or cyclic mode operation depending on the wettability of the porous plate.

With the evaporation mechanism, the phase change occurs at pressure levels above the triple point. The absence of a solid ice layer to prevent liquid from passing through the porous plate requires that some other mechanism retain the liquid if supply pressure to ambient pressure differentials are to be greater than the vapor pressure drop. Surface tension supplies the necessary restraining force for preventing liquid from passing through the porous plate.

The head of liquid which a pore can retain by surface tension is inversely proportional to the equivalent radius of the restriction. If the pore size is too large to support the water feed pressure, breakthrough of liquid will occur when the input heat flux prevents operation in the sublimation mechanism. The surface of the meniscus formed by the liquid restrained in the porous plate is exposed to the lower pressure ambient allowing evaporation to satisfy the heat rejection requirement. Similar to the sublimation mechanism, the evaporation temperature is governed by the vapor pressure drop of the porous plate in conjunction with the liquid-vapor equilibrium pressure characteristic of the coolant.

To determine the evaporation sink temperature, the wettability characteristics of the porous plate must be known. If the porous plate has nonwetting characteristics (hydrophobic), the liquid is restrained at the upstream surface of the porous plate. Thus, the vapor pressure drop characteristics of the porous plate must be known to calculate the evaporation temperature. If the porous plate has wetting characteristics (hydrophilic), the liquid is restrained at the downstream end of the pore, and vapor pressure drop characteristics are not required to predict the sink temperature.

To analyze the hydrophobic case in the evaporation mode, the mass rates through the various pore sizes would have to be determined assuming constant heat of vaporization, then applied to the free molecular Knudsen equation to determine the evaporant pressure and temperature when the ambient pressure is known. An effective evaporant temperature could then be determined over the entire porous plate.

B4.1 (Continued)

A hydrophilic material would eliminate the need to calculate vapor pressure drop over the porous plate to determine the effective evaporant temperature. Then, since the input heat flux is simply the heat conducted across the liquid layer and the porous plate, the temperature of the heated plate can be expressed as:

$$T_o = T_e + q_o/A \cdot 1/U \tag{8}$$

where T_e is the evaporation temperature corresponding to the ambient pressure and U is the equivalent thermal conductance. The equivalent thermal conductance is then given as:

$$1/U = \delta/k_\ell + t/k_p \tag{9}$$

where k_ℓ and k_p are the equivalent thermal conductivities of the liquid layer and porous plate, respectively. If natural convection is eliminated and no fins are included, k_ℓ is the conductivity of water, and k_p can be expressed as:

$$k_p \simeq k_\ell \; P + k_m (1 - P) \tag{10}$$

where P is the porosity of the plate and k_ℓ and k_m are the thermal conductivities of water and the porous plate metal, respectively.

Increasing input heat flux will cause a direct transition from the sublimation mechanism to the evaporation mechanism if the pores are regular and uniform, such as on a stainless steel plate presently under test, and sufficiently small for surface tension to prevent liquid breakthrough. However, porous plates utilized in previous sublimator designs contain a random distribution of pores with respect to both size and shape causing an operating region which has been called the mixed or cyclic mode, depending on the porous plate wettability. The point of transition for any single pore is dependent on its equivalent radius and, ultimately, the vapor pressure drop produced by the pore.

The mixed mode of cooling will exist for hydrophobic porous plates, where the liquid from those pores which have melted is restrained at the upstream side of the porous plate. In the mixed mode of cooling, phase change occurs at local temperatures above and below the triple point depending on the local pore geometry. As a result of a distribution of pore sizes, an averaging effect exists and, if the plate is of reasonable thermal conductivity, the effective plate temperature has been found to remain constant and very near the triple point for a wide range of heat fluxes.

The mixed modes of cooling are unique in that a wide range of porous structures will exhibit the same heat rejection capability. The smaller pores are the first to undergo the transition from the sublimation to the evaporation cooling mechanism since they present the highest vapor pressure resistance. This is quite fortunate because these smaller pores are more capable of retaining liquid behind the porous plate by surface

B4.1 (Continued)

tension, while the larger ones remain plugged by ice. It is this order of events which allows operation in the mixed mode over a wide range of heat fluxes with liquid supply pressures higher than the water retention capability of the largest pore.

The cyclic mode of cooling will exist for hydrophilic porous plates. In this mode, no ice is present behind the porous plate, and melted water flows into the pores and re-freezes. The new ice then sublimates from the end of the pores. As sublimation continues, the ice interface will progress toward the upstream end of the pores, resulting in an increase of the vapor pressure drop. As the vapor pressure rises above the triple point pressure, any remaining ice will melt and the process then repeats itself.

While this microscopic pore system is cyclical, the macroscopic porous plate system is found to be a steady-state system, maintaining an effective plate temperature very near the freezing point temperature, as did the mixed mode of cooling for hydrophobic plates.

For this application, over the range of cooling loads required, the sublimation/evaporation sink temperature is assumed to be at the $0^{\circ}C$ ($32^{\circ}F$) triple point temperature. The LCG cooling loop passes through a plate-fin aluminum heat exchanger for which film coefficients and pressure drops can be calculated. The conductive path from the LCG heat exchanger is assumed to traverse a 7.6×10^{-5} Meter (0.003") gap of water to the porous plate surface. The surface area required to cool the LCG loop can then be calculated by treating the coolant film coefficient and the water gap conductance as two conductances in series and utilizing Hamilton Standard design procedures for low Reynolds' numbers in the plate-fin heat exchanger.

B4.2 References

1. Sangiovanni, J. J., and Hepner, P.H., "Porous Plate Water Boiler Design Study - Final Report", Contract No. NAS-9-2294, Hamilton Standard Division, United Aircraft, Corp., May, 1965.

2. Kennard, E. H., Kinetic Theory of Gases, McGraw-Hill, New York, 1939.

3. "A Fundamental Study of Sublimation through a Porous Surface", Contract No. NAS 9-7969, Rice University, Houston, Texas, July 30, 1971.

B5.0 LOW BACK PRESSURE SUBLIMATOR

The design of the Low Back Pressure sublimator differs from porous plate sublimators in that a non-metallic open cell foam cover is used for the sublimation regime instead of a porous plate. This foam is placed on the surface of the working fluid heat exchanger with feedwater passages incorporated to distribute the expendable liquid over the surface of the heat exchanger during start up. As a heat load is applied, the expendable liquid flows onto the heat exchanger surface, boils, then freezes to form an ice layer over the HX surface and then sublimates. As the expendable ice layer sublimates, more feedwater flows onto the heat exchange surface to continue the process. Under a no or low heat load condition, the feedwater passages are blocked by complete ice formation on the HX surface, preventing further feedwater incursion.

The thermodynamic analysis of the heat transfer modes is identical to the analysis presented for the porous plate sublimator operation. Difficulty arises, however, in the analysis of the conduction of heat through the liquid/ice layer along the heat exchanger wall. This difficulty is a result of the variable water and ice layer thicknesses that can develop over the heat exchanger surface due to the non-rigidity of the open cell foam. For a solid porous plate, the ice/water total gap between the heat exchange surface and the sublimation region is fixed, making a heat transfer analysis straight forward. For the Low Back Pressure sublimator with a variable gap thickness, an accurate analysis of the heat transfer process is not feasible, but rather must be accomplished by empirical procedures.

APPENDIX C

HRS CONCEPTS

DEFINITION AND EVALUATION

C1.0 INTRODUCTION

For the preliminary HRS screening, 13 candidates were selected. These consisted of the four water boilers, six flash evaporators and three sublimators listed in Table C1-1. This Appendix contains a description of each candidate and the details of the evaluation.

TABLE C1-1

HRS CONCEPTS

Remote Storage H_2O Boiler with Wick Wetness Sensor	Pneumatic Nozzle Spray Flash Evaporator
Remote Storage H_2O Boiler with LCG Delta T Control	LP Ultrasonic Nozzle Spray Flash Evaporator
Remote Storage H_2O Boiler with Pressure Feed	LP Mechanical Atomizing Nozzle Spray Flash Evaporator
Integral Storage H_2O Boiler	LP Rotating Drum Flash Evaporator
High Pressure (HP) Hydraulic Nozzle Spray Flash Evaporator	Apollo Type Sublimator
Low Pressure (LP) Impingement Nozzle Spray Flash Evaporator	Replaceable Plate Sublimator
	Low Back Pressure Sublimator

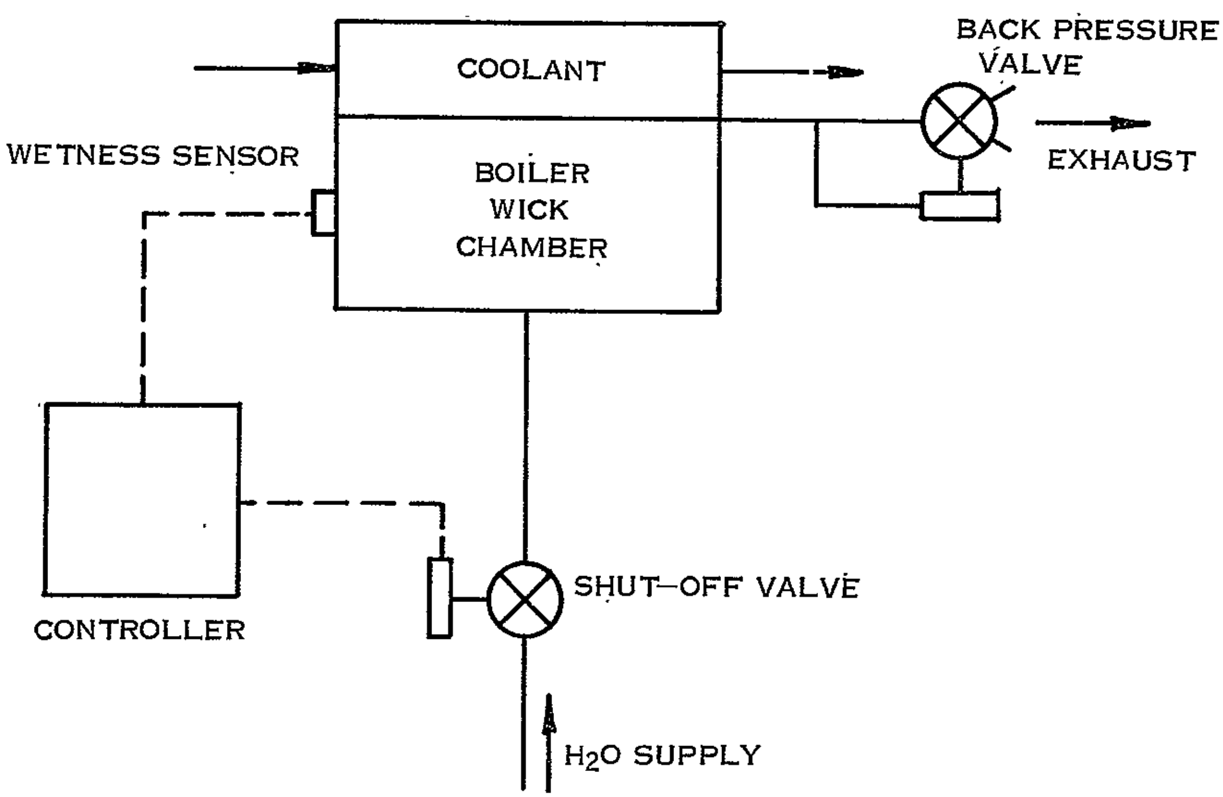
C2.0 CANDIDATE DESCRIPTION

C2.1 Water Boiler Concept Definition

The water boiler is an expendable thermal control concept which utilizes the heat of vaporization of water to satisfy the system heat rejection requirements. Two basic types of water boiler were considered; remote water storage and integral water storage. In both cases, the temperature of the evaporant is governed by the pressure at the boiling surface. This pressure is controlled by a back pressure valve which may be either temperature sensing or pressure sensing.

In the case of the remote storage water boiler, the feedwater is stored separate from the boiling element. This type of device requires active control of the rate at which feedwater is fed to the boiler wick chamber (too high a feed rate results in flooding and too low a feed rate results in flow starvation). The feedwater rate control can be accomplished using a wick wetness sensor and controller, a coolant temperature sensor and controller or a pressure regulator.

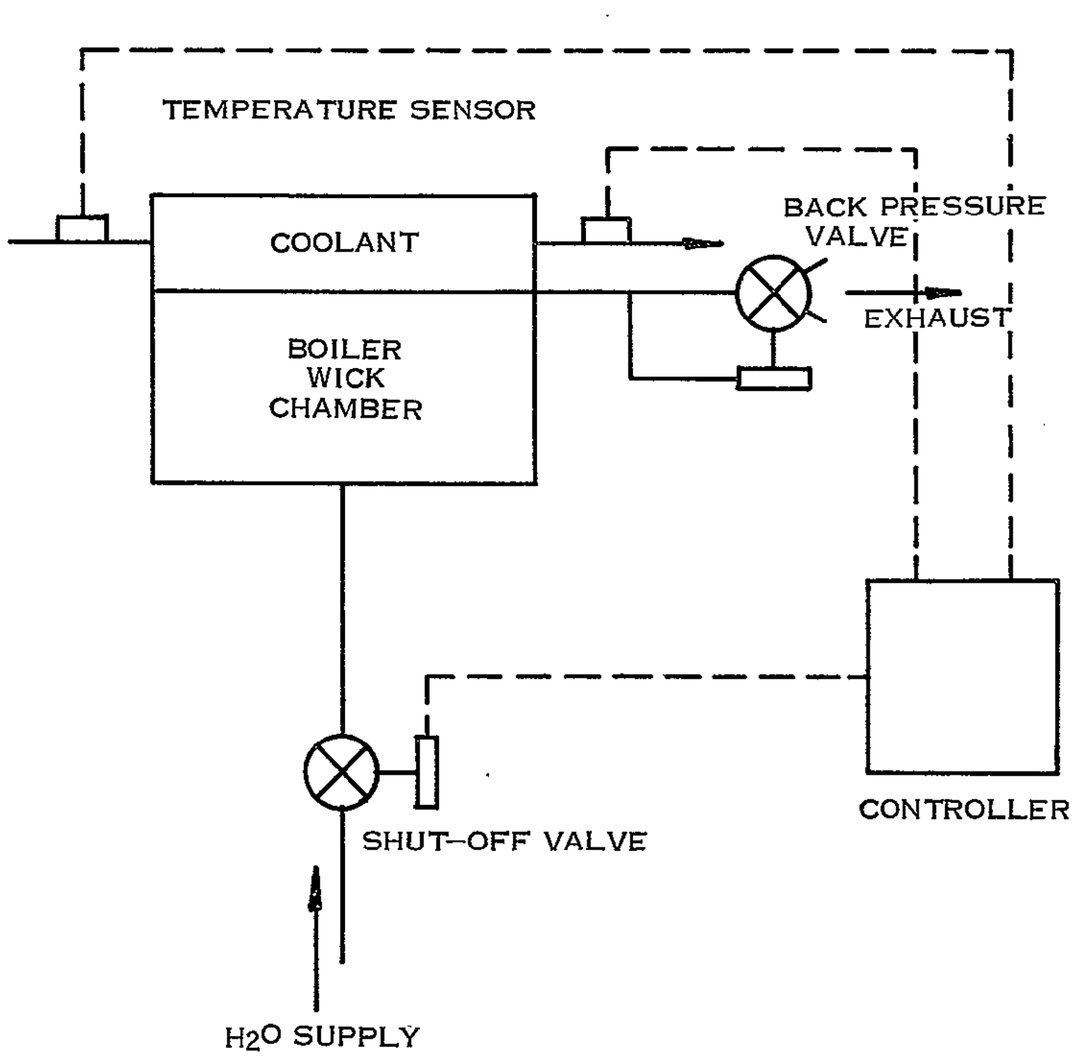
Figure C2-1 depicts the water boiler with wetness sensor. The wetness sensor measures electrical conductance in the wick and sends a signal to the controller which modulates the flow of feedwater to the boiler.



REMOTE STORAGE H_2O BOILER WITH WICK WETNESS SENSOR
FIGURE C2-1

C2.1 Continued

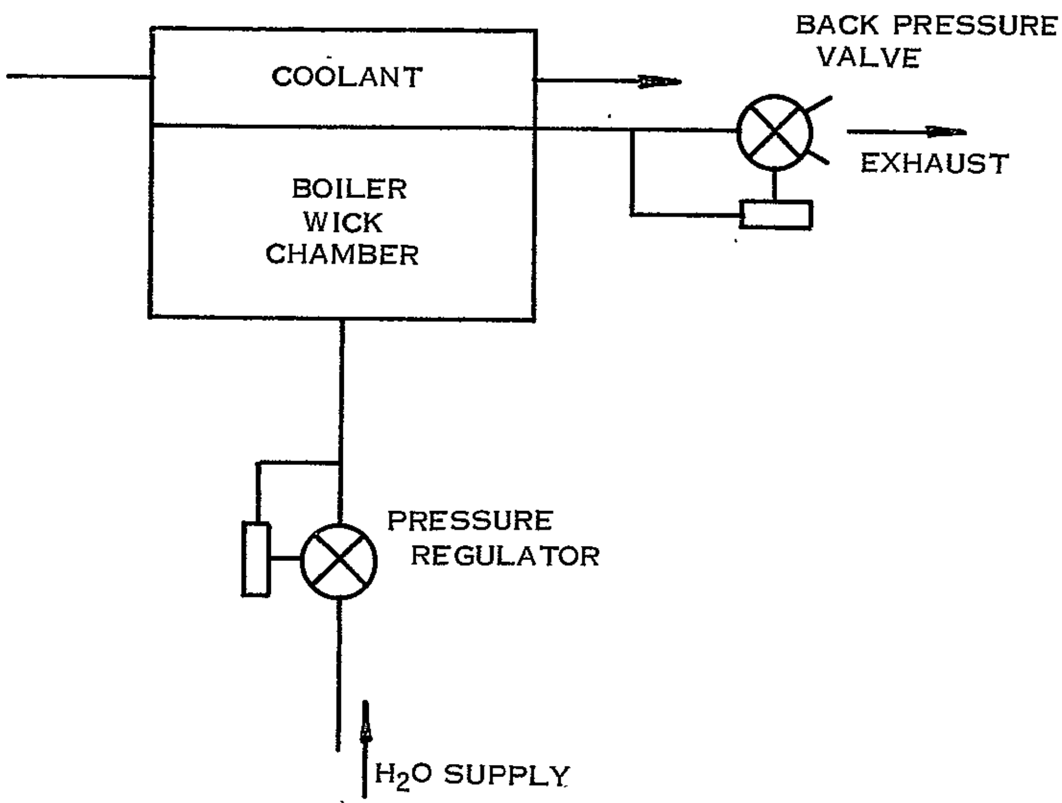
Figure C2-2 depicts the system with coolant temperature sensors. In this case, feedwater flow is modulated by the controller as a function of the ΔT between the two temperature sensors.



REMOTE STORAGE H_2O BOILER WITH LCG ΔT CONTROL
FIGURE C2-2

C2.1 Continued

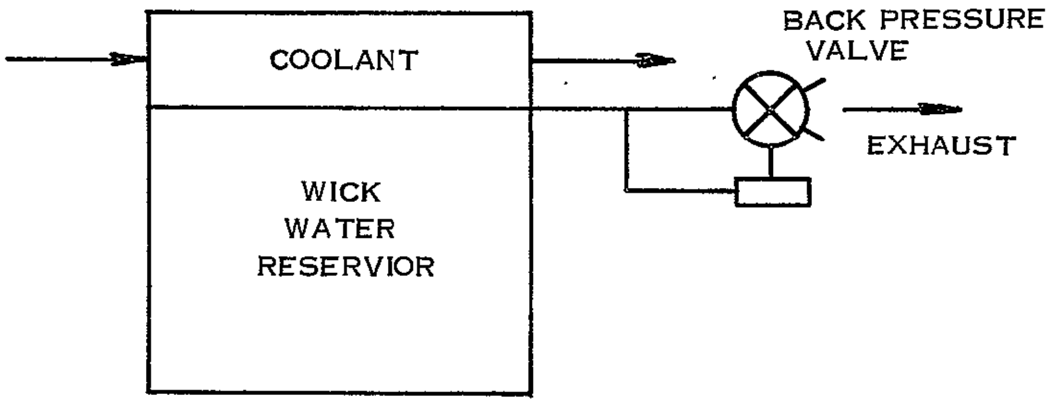
Figure C2-3 depicts the system with the pressure regulator. In this case, feedwater flow is modulated as required to maintain a constant pressure within boiler wick chamber.



REMOTE STORAGE H_2O BOILER WITH PRESSURE FEED
FIGURE C2-3

In the case of the integral water storage boiler depicted by Figure C2-4, all of the water is stored in a wick filled reservoir which is connected directly to the evaporant surface. Alternate layers of dacron felt are preloaded against the heat transfer surface to ensure flow of water to replace the water vaporized at the heat transfer surface.

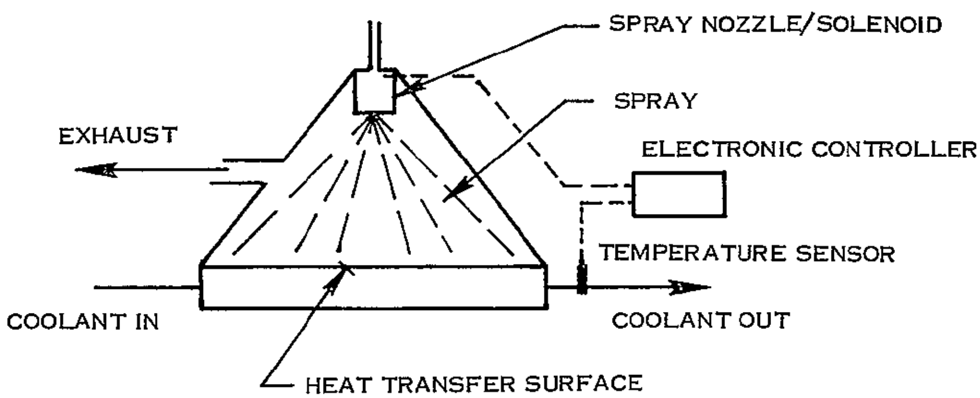
C2.1 Continued



INTEGRAL STORAGE H_2O BOILER
FIGURE C2-4

C2.2 Flash Evaporator Concept Definition

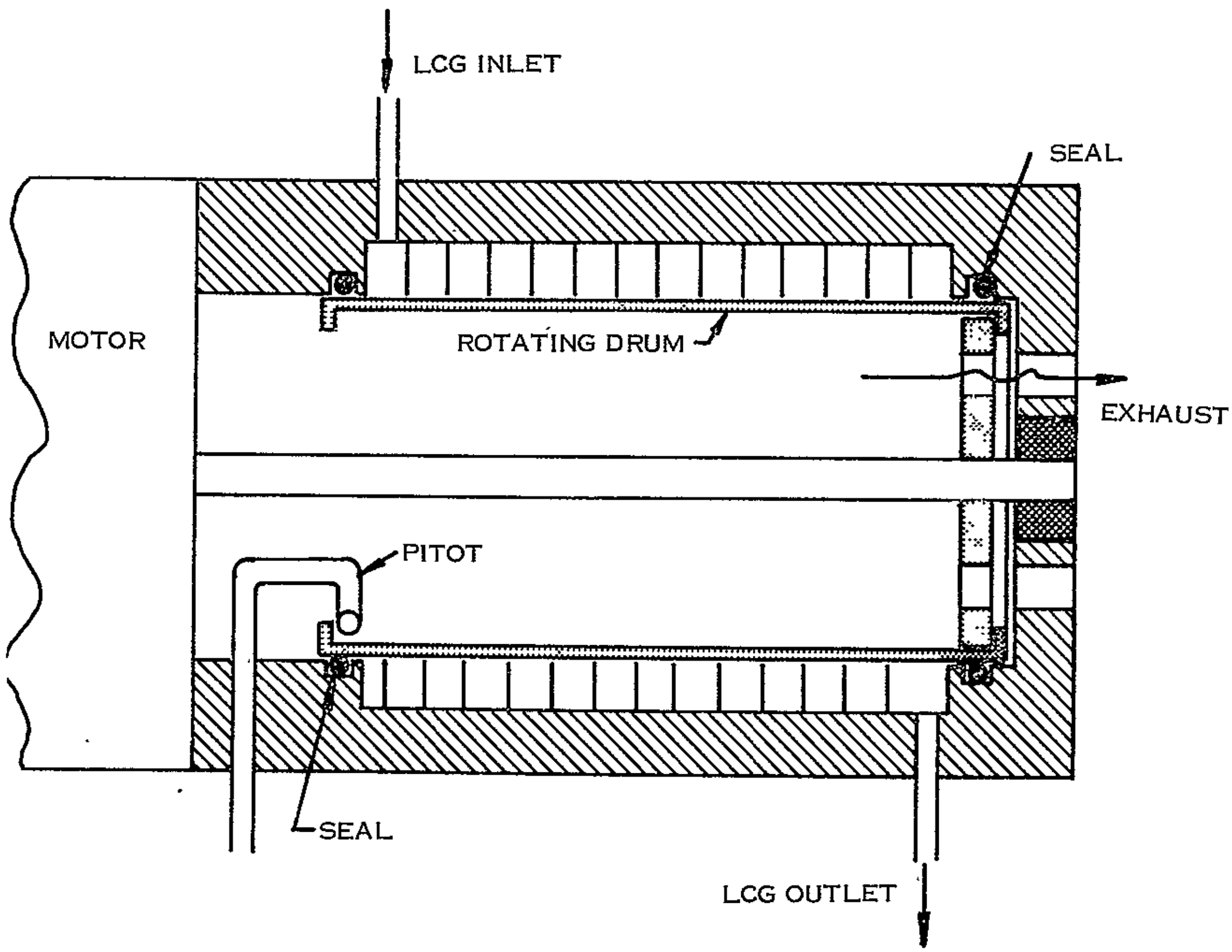
Two basic types of flash evaporators were considered; the spray nozzle flash evaporator and the rotating drum flash evaporator. The spray nozzle flash evaporator, shown schematically in Figure C2-5, utilizes an atomizing spray nozzle to direct a fine mist of water against a heat transfer surface as a function of heat load. As heat is applied at the heat transfer surface, the water vaporizes and is vented to vacuum through the exhaust port. The exhaust port is sized to maintain the vapor pressure near the triple point so as to maintain a constant sink temperature under average load conditions. The coolant outlet temperature is monitored and the spray flow rate is modulated by varying the pulse rate of the nozzle solenoid valve to maintain the coolant outlet temperature constant.



SPRAY NOZZLE FLASH EVAPORATOR
FIGURE C2-5

C2.2 Continued

In the rotating drum flash evaporator shown in Figure C2-6 feedwater is supplied to the inside of a rotating drum through a pitot tube. When more water is supplied than is being evaporated, the back pressure against the pitot shuts off the feedwater supply.



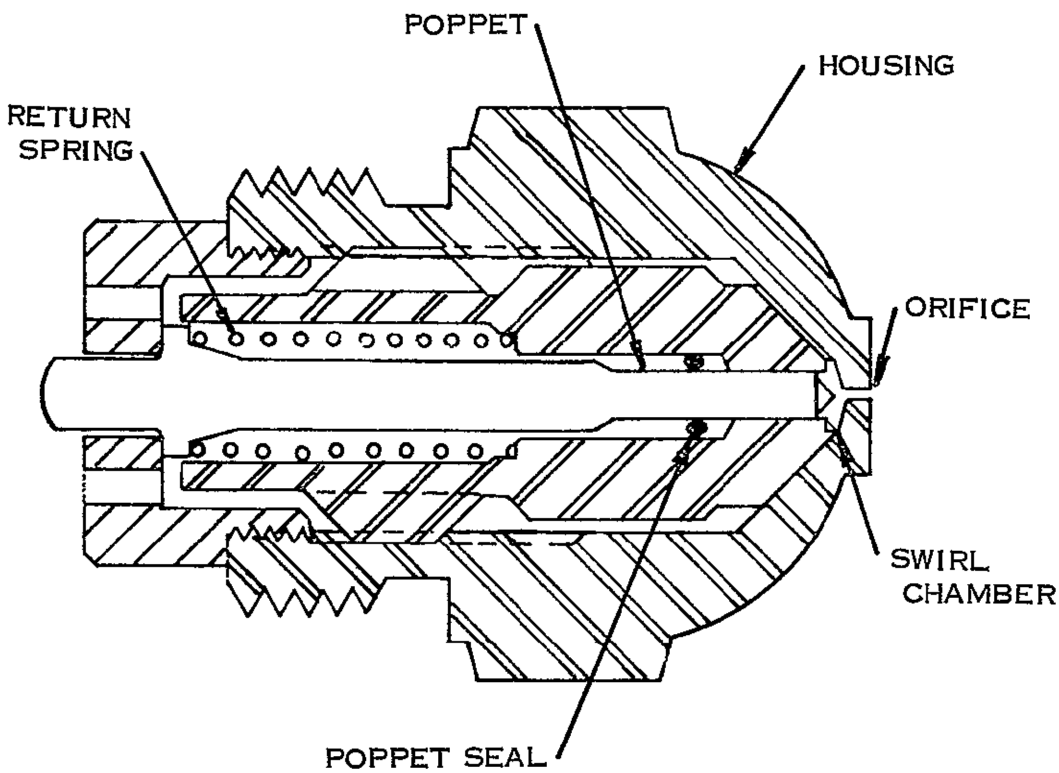
ROTATING DRUM FLASH EVAPORATOR
FIGURE C2-6

The atomizers listed in Table C2-1 were evaluated for use in the spraying flash evaporator. From this table of atomizers four basic types were selected for detail evaluation: (1) solid injection, using pressure nozzles, (2) two-fluid atomization, where the liquid is disintegrated by a high-velocity stream of gas, (3) atomization by rotating disks or cups, and (4) atomization by sonic or mechanical vibrations.

C2.2 Continued

The most widely used method for atomizing liquid fuels is solid injection by pressure nozzles. This method depends primarily on the flow of liquid through an orifice to form a high velocity jet which atomizes upon leaving the nozzle. There are two types of pressure-jet atomizers: (1) plain-orifice type, and (2) centrifugal swirl types.

In a simple swirl-type atomizer Figure C2-7, the liquid is fed through tangential ducts, slots, or channels into a circular swirl chamber. As the liquid spins or swirls around, its angular velocity increases inversely as the radius of swirl. The rotating mass of liquid flows towards the discharge orifice which has a small diameter as compared with that of the swirl chamber.



HYDRAULIC NOZZLE
FIGURE C2-7

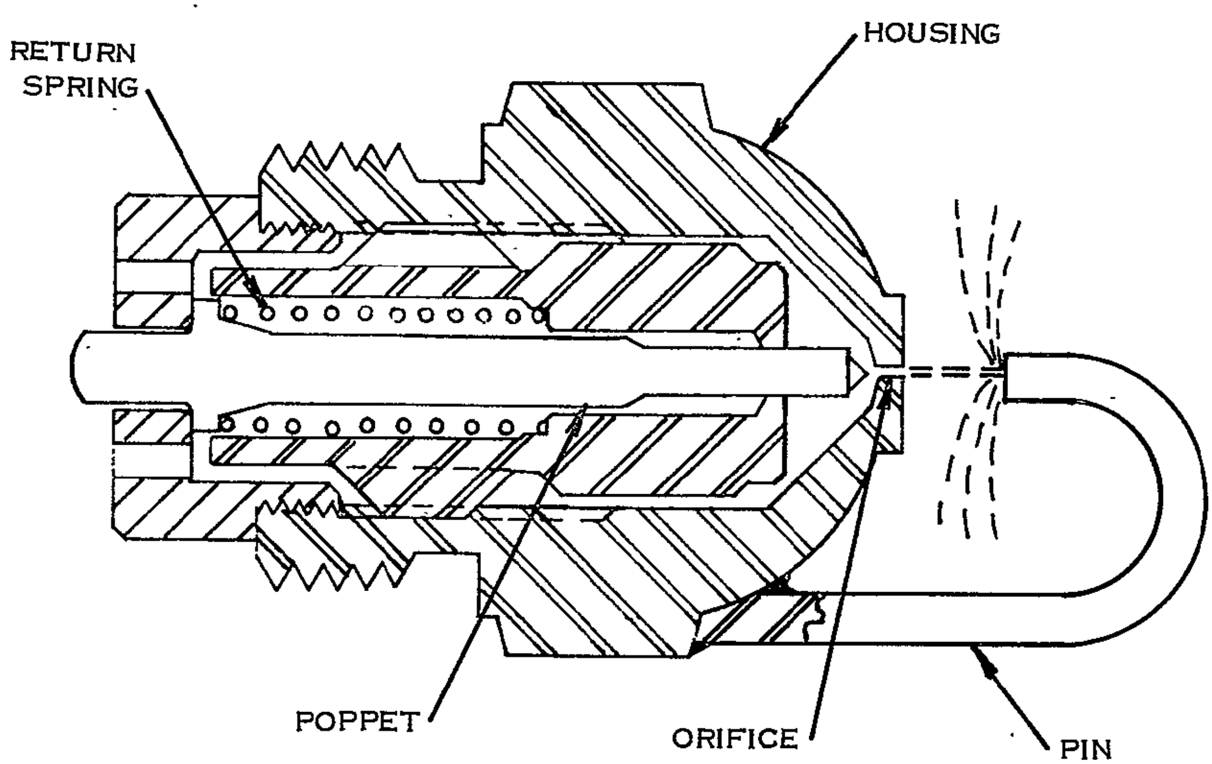
The liquid is under the influence of two main forces: (1) translational force moving the liquid axially forward, and (2) the centrifugal force which makes the liquid swirl. Under these forces the liquid emerges from the orifice as a divergent cone.

C2.2 Continued

Atomization by solid injection with the plain orifice utilizes a metal lip or other surface against which the jet of fluid impinges (Figure C2-8). This type of device can operate with low supply pressures.

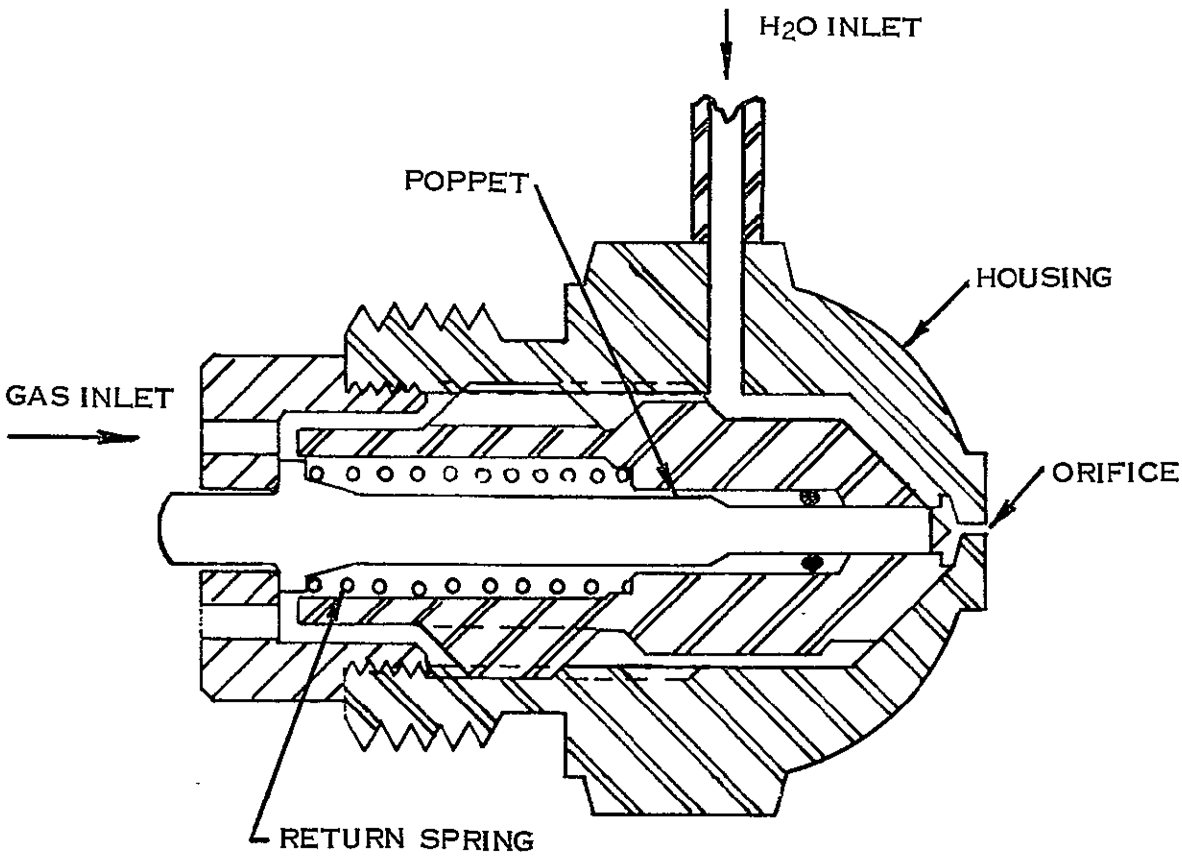
In two-fluid atomization, the liquid is broken up by impingement with a high-velocity stream of gas. In two-liquid atomizers (Figure C2-9) the air and liquid streams come together inside the nozzle or else outside as the two streams leave the nozzle. The chief advantage of two-fluid atomization is that a greater fineness of atomization can be achieved. Liquids can be atomized necely but more power is required to spray at a given rate than in a pressure nozzle because the fluid is more finely divided.

Rotating atomizers employ disks, cups or other shapes rotating at high speed by electric motors, or by air or steam turbines (Figure C2-10). A spray of almost uniform drop size can be produced. In these methods of atomization, liquid flows to the edge of the disk and is collected until the centrifugal force on the mass is greater than the force due to surface tension. A drop is then thrown off. The low efficiency of the rotating assembly requires an excess of air or electrical power to drive the disk at the correct speed.



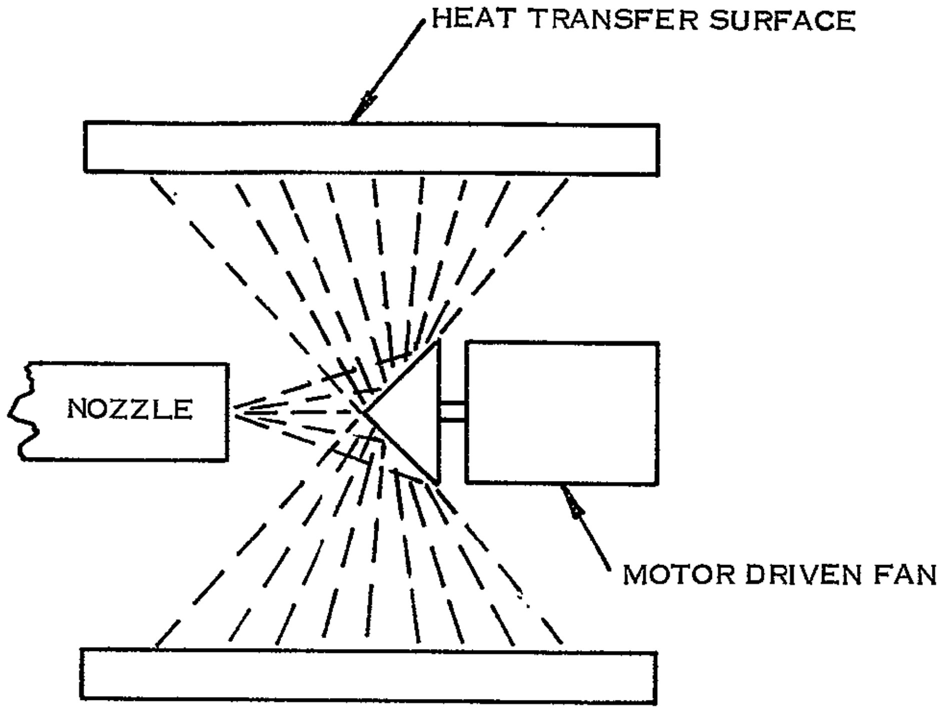
IMPINGEMENT NOZZLE
FIGURE C2-8

C2.2 Continued



PNEUMATIC NOZZLE
FIGURE C2-9

C2.2 Continued



ROTATING ATOMIZER
FIGURE C2-10

TABLE C2-1

DESIGN FEATURES AND SPRAY CHARACTERISTICS OF VARIOUS TYPES OF ATOMIZERS

(Reference 1)

Atomizer	Design Features	Spray Characteristics
Centrifugal Pressure Nozzles Simplex	Circular orifice outlet preceeded by swirl chamber with one or tangential inlets. Slotted distributor may be used.	Hollow conical pattern with angles generally between 30° and 120°. Moderate droplet size; finest atomization at low capacities, high pressures, and wide spray angles. Capacities extend up to

Reference 1 - Tate, R. W. "Sprays and Spraying For Process Use" Chemical Engineering July 19, 1965

C2.2 Continued

Atomizer	Design Features	Spray Characteristics
		thousands of gallons per hour. For given nozzle, discharge varies approximately with square root of operating pressure.
Solid cone	Similar to simplex nozzle but with special core or axial jet to fill in center of conical pattern.	Solid (full cone) nozzles available in extremely high capacities, but also range down to 1 gph. or lower. Atomization at low capacities similar to that of corresponding hollow-cone nozzles, but occurrence of coarser droplets as tangential flow component is dimished. Droplets at center of pattern usually larger than those near edge.
Square spray	Swirl chamber construction with special orifice outlet configuration to accent corners of spray pattern.	Relatively solid pattern, with somewhat coarser droplets than most hollow-cone types. Multiple-nozzle arrangement recommended where uniform coverage of large areas is required.
Bypass (spill)	Simplex construction, but with return flow line at rear, side, or front of swirl chamber and valve to control quantity of liquid removed from chamber.	Virtually infinite turndown ratios possible since nearly all the liquid can be bypassed and returned to supply. Supply pressures normally held constant, with flow rate modulated by adjusting bypass pressure. Hollow-cone pattern, with slight increase in spray angle as flow is reduced. Maximum discharge rates up to at least 200 gph.
Duplex	Circular orifice combined with two sets of distributor slots, each having separate liquid supply.	Pattern and droplet size similar to simplex nozzle. However, greater flow range possible by programming liquid through the two separate

C2.2 Continued

Atomizer	Design Features	Spray Characteristics
		distributor systems. Spray angles widest near maximum discharge, but become narrower as flow is reduced.
Dual orifice	Two concentric orifice-distributor systems (one within the other), each having separate liquid supply. External or integral flow-divider valves required.	Even larger flow ranges possible. (Turn-down ratios as high as 50:1.) Low capacities achieved with inner (primary) orifice and distributor with transition to combined primary-secondary operation giving much larger flow rates. Relatively constant spray angle and degree of atomization throughout most of operating range.
Fan-Spray Nozzles Elliptical or oval orifice	Orifice formed by intersection of V-groove with cylindrical liquid inlet.	The most popular type of fan-spray nozzle, producing narrow elliptical pattern with tapered edges that provide uniform distribution when overlapped. With careful design and manufacture, atomization quality is virtually equivalent to corresponding centrifugal pressure nozzles. Extremely small carbide orifices (1 gph. at 500 psi) possible for high-pressure coating operations. Excellent atomization and patterns with viscous materials. At other extreme, orifices exceeding 0.5 in. permit several thousand gallons per hour flow at low pressures. Can be designed for wide range of spray angles; approximately 110° down to straight stream.

C2.2 Continued

Atomizer	Design Features	Spray Characteristics
Rectangular orifice	Liquid sheets may also be produced by various types of rectangular or slotted orifices. Orifice may be formed at end of converging tube, or may be cut perpendicular to surface of cylindrical tube to produce curved slot.	Though not as popular as elliptical type, some commercial nozzles are designed with rectangular or slit-type orifices. Sheet width and thickness controlled by orifice dimensions and approach passage. Little available information on pattern or atomization quality.
Deflector	Liquid discharges through plain circular orifice and impinges on curved deflector plate. Spray is deflected about 75° from nozzle axis.	Sometimes referred to as flooding nozzle, this type produces relatively coarse droplets, particularly at low pressures. Wide spray angles possible, with flow rates ranging from about 10 to several thousand gallons per hour. Because nozzle passages are relatively large, plugging is minimized.
Impinging jet	Two or more liquid jets collide outside nozzle, producing liquid sheet perpendicular to plane of the jets. Circular liquid sheet is formed by impingement of fully opposed concentric jets.	Principal advantage of this atomizer is isolation of different liquids until they impinge outside nozzle. High stream velocities and wide impingement angles necessary to approach spray quality obtainable with other types. Symmetric flat pattern and good atomization possible only if extreme care is exercised during manufacture to align jets. Depending on operating conditions, mean droplet sizes from 100 to 1,000 microns reported. Bimodal droplet size distributions typical.

C2.2 Continued

Atomizer	Design Features	Spray Characteristics
Fluid Atomizers		
Internal mixing	Gas and liquid mix within nozzle before discharging through outlet orifice. Fluids sometimes supplied through tangential slots to encourage turbulence and thorough mixing. Liquid usually metered externally since flow is affected by interaction with gas.	Capable of extremely fine atomization, especially at high air/liquid ratios. Since pneumatic energy is inefficiently utilized, power consumption is excessive at large capacities. However, particles in aerosol range obtainable with sufficient gas flow and pressure. Spray angles tend to be narrow (30° to 60°), and are not as well defined as in other atomizers.
External mixing	High-velocity gas impinges on liquid at or outside orifice. Pneumatic energy, however, is still utilized for liquid breakup. Back pressures are avoided because there is no internal communication between gas and air, and device may be used as metering nozzle.	This type somewhat less efficient than internal-mixing two-fluid nozzles, and higher air/liquid ratios are usually required. Large flow rates uneconomic because of high air consumption. (Steam or other gases may also be used.) High-viscosity liquids can be atomized effectively. Low-flow nebulizers produce submicron droplets.
Siphon (aspirating)	Pneumatic atomizer in which liquid is aspirated by gas and siphoned through height of several inches.	For given nozzle, flow rate and droplet size extremely sensitive to air pressure and siphon height (or gravity head). Device is most effective in 0.1 to 3.0 gph. range. Spray angles are narrow.
Sonic (gas generator)	Intense sonic radiation (as high as 160 db) generated by Hartmann whistles or other gas generators focused on liquid sheets or streams to implement breakup.	Sonic or ultrasonic compressions and rarefactions are claimed to improve breakup and possibly produce more uniform droplets. Sonic and pneumatic effects are difficult to isolate from each other. Little information on atomization efficiency and spray quality. Commercial models in 0.5 to 1,000 gph range available.

C2.2 Continued

Atomizer	Design Features	Spray Characteristics
Rotary Atomizers Spinning disk	Liquid introduced at center of high - speed rotating disk several inches in diameter. Disks may be smooth plates, bowls or saucers with curved, sharp edges. Many, however, are designed with straight or curved vanes or slots to guide liquid to periphery. Some installation involve multiple-tier designs or concentric sets of vanes.	360° spray pattern, with improved atomization as peripheral speed increases and flow rate is reduced. At low flows, droplets form near edge of disk; at higher feed rates, liquid filaments or sheets develop and break up because of instability. Nearly uniform atomization possible with small disks operated at low capacities and extremely high speeds. At higher flow rates (ranging up to several thousand gallons per hour), droplet-size spectrum is rather broad, similar to many nozzles. Usually installed in cylindrical or conical chamber where umbrella-like spray is produced by downward gas currents.
Rotary Cup	Similar to disk, but usually smaller in diameter and shaped as elongated bowl or cup. Sometimes operated with air blast around periphery. Various methods of introducing feed.	Liquid fed at one end of cup progresses as smooth swirling film to opposite end where 360° sheet perpendicular to cup axis is released. Depending on design, rotational speed, and flow rate, liquid film breaks down into ligaments and droplets of various sizes and at various distances from cup edge.
Spinning nozzle	Distinguished from above rotating devices because of peripheral orifices which form liquid jets through centrifugal action.	Jet breakdown sometimes aided by hydraulic pressures in these rotary nozzles of "slingers". Various models available for diverse applications, but seldom used as industrial atomizers.
Circular Types Plain orifice	Nozzle having plain circular orifice that produces straight stream.	This is simplest possible nozzle. Often specified where high impact or momentum is required. Atomization virtually nil except at very high pressures; however,

C2.2 Continued

Atomizer	Design Features	Spray Characteristics
		fine droplets are produced at several thousand pounds per square inch because of jet instability and relative velocity of ambient gas.
Movable poppet	Conical liquid sheet formed by annular gap between cylindrical orifice and conical poppet that moves axially under force of liquid pressure. As poppet (restrained by spring) is pushed further out, annular discharge area enlarges, magnifying effect of pressure on flow.	Liquid pattern determined entirely by orifice-poppet configuration, and good spray quality is difficult to achieve unless parts are precisely fabricated and aligned. Poppet vibration can also be problem. Practical spray angle range is 45° to 120°, and angle remains fairly constant over wide operating range.
Vibrative	Electrically activated vibrating reed flicks droplets from liquid reservoir. In another device, liquid flowing across surface of vibrating bar is atomozed at zones of maximum amplitude. Maximum efficiency claimed at resonant frequencies.	Ideally, vibrative atomizers are capable of generating very uniform droplets; this has been demonstrated with reeds oscillating at fixed frequency. With vibrating bars, capillary waves are formed which break free from the liquid film, forming individual droplets in 100 to 1,000 micron range. Particle size can be changed by varying vibrational frequency.
Ultrasonic (transducer)	Similar to above in principle, liquid is fed through or over a transducer and horn excited at ultrasonic frequencies to provide the small wave-lengths necessary for fine atomization. System requires signal generator, power supply, and amplifier.	This device is relatively recent, and further development is indicated before completely satisfactory spray can be achieved. Coarse droplets have been observed; possibly caused by a cavitation process. Nevertheless, the design principle is well suited for low flow rates that are difficult to achieve with certain other types of atomizers. These

C2.2 Continued

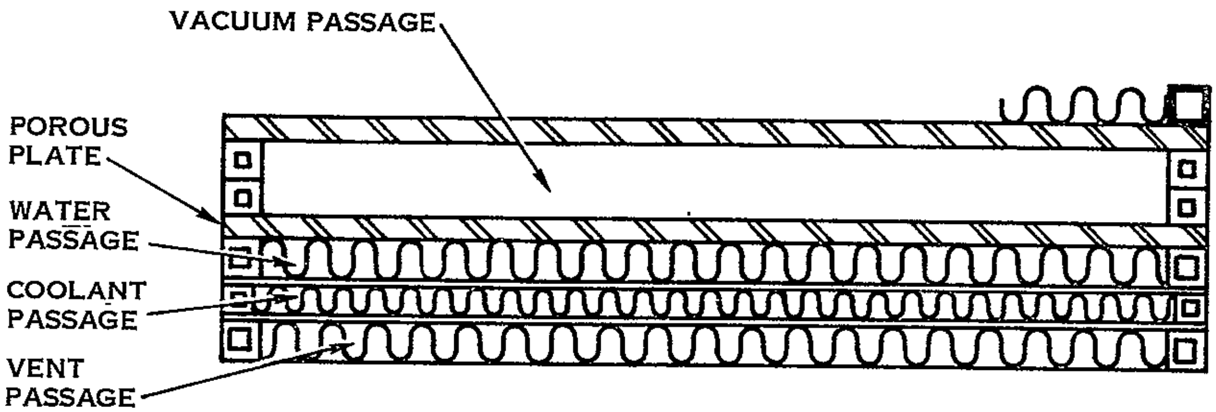
Atomizer	Design Features	Spray Characteristics
		transducer devices should not be confused with sonic or ultrasonic atomizers utilizing gas generators.
Electrostatic	Liquid film or jet subjected to intense electric field that overcomes surface tension forces, producing discrete droplets. Current research on capillary tubes and conical disks directly charged at high voltage. In other systems, charge is induced on droplets by electrodes outside conventional nozzle.	Droplet size is function of physical and electrical properties of liquid, electrical potential, flow rate, and construction of atomizer. One practical problem is that of suitable power supply; sufficiently rugged, safe, and inexpensive for industrial applications.

C2.3 Sublimator Concept Definition

Two basic types of sublimators were evaluated. These were the high back pressure sublimator and the low back pressure sublimator. Further, there were two configurations of the high back pressure sublimator defined and evaluated; the non-replaceable porous plate sublimator (as used on the Apollo PLSS) and the replaceable porous plate sublimator.

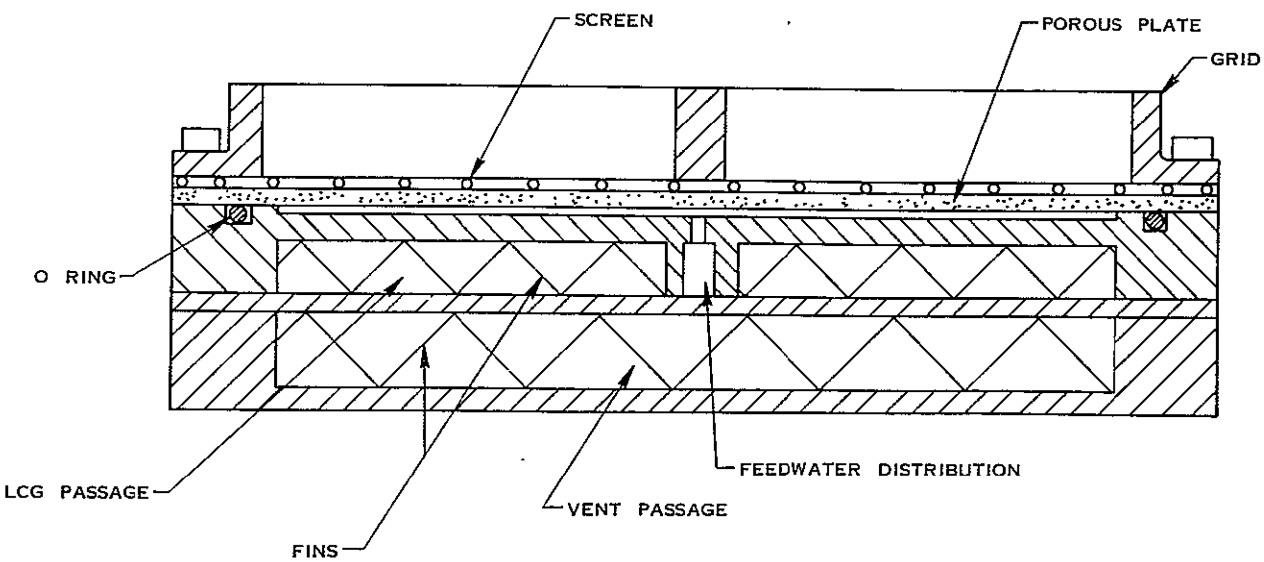
In the high back pressure, non-replaceable porous plate sublimator, Figure C2-11, water is introduced to the sublimator core between the surface to be cooled and a plate of porous material. The water, which is under pressure, flows partially through the porous plate until it is affected by the space vacuum and freezes. Heat is conducted from the hot surface through the liquid water and supplementary finning to the porous plate where the ice exposed to space sublimates at a rate directly proportional to the heat load thus, this type of device is totally self-regulating, With the non-replaceable plate sublimator, the porous plates are an integral part of the heat exchanger which is a brazed assembly.

C2.3 Continued



APOLLO-TYPE SUBLIMATOR
FIGURE C2-11

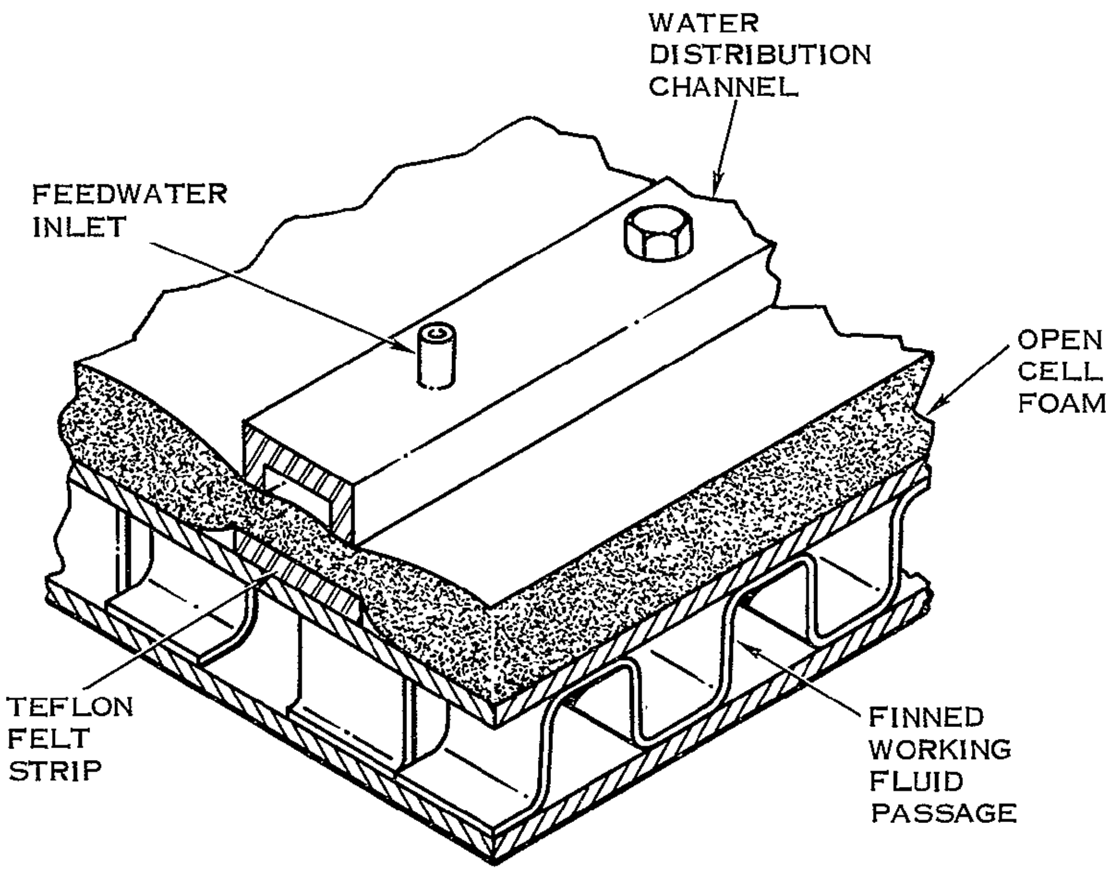
The replaceable plate sublimator, Figure C2-12, consists of a heat exchanger assembly which contains the LCG and vent loop passages and the feedwater distribution channel; a porous plate, a screen; and a support grid. The vent loop is cooled via heat transfer to the LCG loop which is, in turn, cooled by heat transfer to the porous plate. The system heat is rejected by feedwater sublimation through the porous plate. The support grid is used to restrain the porous plate and to minimize plate deflection under pressure load. The screen provides point contact between the grid and the porous plate to minimize back pressure in the area adjacent to the grid to prevent breakthrough.



REPLACEABLE PLATE SUBLIMATOR
FIGURE C2-12

C2.3 Continued

The low back pressure sublimator, Figure C2-13, utilizes non-metallic open cell foam cover for the sublimation regime. This foam is placed on the surface of the coolant heat exchanger with feedwater passages incorporated to distribute the expendable liquid over the surface of the heat exchanger during start up. As a heat load is applied, the expendable liquid flows onto the heat exchanger surface, boils, then freezes to form an ice layer over the heat exchanger surface and then sublimates. As the expendable ice layer sublimates, more feedwater flows onto the heat exchange surface to continue the process. Under a no or low heat load condition, the feedwater passages are blocked by complete ice formation on the heat exchanger surface, preventing further feedwater incursion.



LOW BACK PRESSURE SUBLIMATOR
FIGURE C2-13

C3.0 CONCEPT EVALUATION

Each of the 13 concepts was evaluated using the absolute criteria. In the case of the hydraulic spray nozzle flash evaporator, two operating pressures were considered; 27.6 KPa (4 psia) suit operating pressure and 248 KPa (36 psia) vehicle water supply pressure. The results of the evaluation to the absolute criteria are included in Table C3-1.

TABLE C3-1

HRS EVALUATION TO ABSOLUTE CRITERIA

Concept	Safety	Performance
Remote storage water boiler with wick wetness sensor	Acceptable	Reject: Inadequate measure of total wick water quantity thus high probability of dry spots or flooding.
Remote storage water boiler with LCG ΔT control	Acceptable	Reject: Sensing and control errors are too great and can result in flooding of unit.
Remote storage water boiler with pressure regulator	Acceptable	Reject: Regulator accuracy requirements are too stringent and control errors can result in flooding of unit.
Integral storage water boiler	Acceptable	Acceptable.
Hydraulic nozzle spray flash evaporator 27.5 KPa (4 psia)	Acceptable	Reject: Water will freeze before reaching heat exchanger surface (see Appendix D for analysis and test results).
Hydraulic nozzle spray flash evaporator 248 KPa (36 psia)	Acceptable	Acceptable. (See Appendix D for analysis.)
Low pressure impingement nozzle spray flash evaporator	Acceptable	Reject: Potential problems due to ice build upon pin. Low velocity of spray could result in ice formation before reaching the heat transfer surface.

C3.0 Continued

Concept	Safety	Performance
Pneumatic nozzle spray flash evaporator	Acceptable	Acceptable.
Ultrasonic nozzle spray flash evaporator	Acceptable	Reject: Atomized water does not have sufficient velocity to reach heat transfer surface before ice formation.
Mechanical atomizing nozzle spray flash evaporator	Acceptable	Acceptable.
Rotating drum flash evaporator	Acceptable	Reject: Basic concept is complex requiring a dynamic seal between LCG loop and vacuum and rotating heat exchanger. Won't meet performance as slave water in unit prevents reaching the non-venting mode within five minutes. Also, potential for ice formation could make unit inoperative.
Apollo-type sublimator	Acceptable	Reject: Large slave volume prevents reaching non-venting mode in five minutes (required more than 30 minutes during Apollo).
Replaceable plate sublimator	Acceptable	Acceptable.
Low back pressure sublimator	Acceptable	Reject: Complex feedwater distribution configuration. Back pressuring foam prone to self-destruction if it becomes saturated with water (turns to ice restricting flow to ambient and over pressures foam). May be difficult to match feedwater flow with heat rejection needs. Feedwater felt strips will cold flow with time which may upset flow/heat rejection balance. Concept offers no advantages over replaceable plate sublimator.

C3.0 Continued

The five concepts which were compliant with the absolute criteria were then evaluated against the relative criteria as summarized in Table C3-2. This evaluation resulted in identification of two competitive flash evaporator concepts and one competitive sublimator concept for configuration optimization.

TABLE C3-2

HRS EVALUATION TO RELATIVE CRITERIA

Concept	Development/Availability	Maintenance
Integral storage water boiler	Not competitive. Requires development of reliable gas venting capability.	Not competitive. IR&D testing has demonstrated that only way to prevent flooding during recharge is to use a wick feed. Air inclusion in wick can result in an incomplete charge which is not possible to detect. Wicks also require considerable maintenance which could result in replacement and retest after each flight. The critical interface between the wick and the heat transfer surface requires elaborate testing to verify proper installation.
Hydraulic nozzle spray flash evaporator 248 KPa (36 psia)	Competitive	Competitive.
Pneumatic nozzle spray flash evaporator	Competitive	Competitive.
Mechanical atomizing nozzle spray flash evaporator	Not competitive - requires development of a high speed vacuum compatible motor	
Replaceable plate sublimator	Competitive	Competitive.

APPENDIX D

HYDRAULIC NOZZLE ANALYSIS AND TEST RESULTS

D-1.0 The least complex flash evaporator using a hydraulic nozzle would be one capable of operating at the suit operating pressure. Thus the potential for using a low pressure nozzle was evaluated. The evaluation consisted of contact with nozzle manufacturer to review the state-of-the-art, a nozzle performance analysis and nozzle performance test.

D-2.0 The nozzle manufacturers listed in Table D-1 were contacted to review the current nozzle state-of-the-art. All of the manufacturers indicated that at least 207 KPa (30 psia) is required to reliably atomize water under low flow conditions.

An analysis was conducted to determine the required operating pressure under the following design conditions:

Water Flow: 4.7×10^{-2} Kg/min (0.75 gph or 0.104 ppm)
Heat Load: 909 watts (3100 Btu/hr)
Heat Transfer Primary Area: 30 in^2

Vacuum Discharge From the Atomizer
Droplet Diameter up to 150 Microns
Mean Droplet Diameter of Approximately 100 Microns

Evaluation of the fluid leaving the pressure nozzles indicates that potential energy in the form of fluid pressure is required for the following:

1) Nozzle Friction
2) Air Resistance
3) Atomization
4) Surface Tension
5) Kinetic Energy

Since the nozzle discharges into a vacuum no air resistance is present.

The atomization energy required to break the fluid down into 100 micron particles, Griffen and Muraszew (Reference 1) is 17.2 KPA (2.5 psi).

The 100 micron water droplets require a pressure of 2.76 KPa (0.4 psi) to maintain surface tension.

The nozzle velocity determines the nozzle friction loss and the droplet kinetic energy which, in turn, determines the required total pressure level. Evaluation of droplet size leaving a pressure nozzle (Tate and Marshall, Reference 2) shows that most nozzles have a droplet distribution very similar to that shown in Figure 1. From this curve it can be seen that

D-2.0 (Continued)

80%-90% of the droplets are between 50 and 100 microns. Droplets greater than approximately 150 microns will yield an excess of spray on the heat transfer surface while droplets less than 50 microns require a higher velocity to prevent freezing before reaching the heat transfer surface. Figure 2 (LTV Reference 3) shows the time in which a water droplet will freeze in a vacuum. The time to freeze a 50 micron droplet in a vacuum ($T_{sat} = -460^{o}$) is 0.007 seconds. For the flash evaporator design the required area of $1.9 \times 10^{-2} m^2$ (30 in^2) can be achieved by a cylinder .1m (4 inches) in diameter by .06m (2-1/2 inches) long. To allow for nozzle spray distribution a 4 inch length would be used resulting in a maximum distance of .11m (4.5 inches) that any droplet must travel. This distance sets the nozzle outlet velocity and the required nozzle inlet pressure of 179 to 262 KPa (26 to 38 psi). The distance of travel for 50 micron particles prior to freezing is presented in Figure 3.

From this analysis it can be seen that the main parameter governing the nozzle pressure requirement is the distance the droplet must travel. This distance is a function of both the heat transfer area and the allowable carryover.

Table D-1
Nozzle Manufacturers Contacted

Spray Engineering	Burlington, Mass.
Spraying Systems	Wheaton, Illinois
Hago Products	Mountainside, N. J.
Bette Fog Nozzle	Greenfield, Mass.
Delavan Manufacturing Co.	Des Moines, Iowa

The final step in evaluating the nozzles consisted of a test program in which several hollow cone, solid cone and flat spray nozzles were tested with a 27.6 KPa (4 psi) supply pressure under both room ambient and vacuum conditions. The results of these tests are summarized in Table D-2 and clearly demonstrate that a pressure significantly higher than the suit operating pressure is required for flash evaporator operation.

D-2.0 (Continued)

Table D-2
Summary of Flash Evaporator Nozzle Testing

Ambient Pressure	Nozzle Description	Inlet Pressure	Results
101 KPa (14.7 psia)	Delavan .5gph 80° Hollow Cone	25.5 KPa (3.7 psig)	No Atomization-Only Large Drops
101 KPa (14.7 psia)	Delavan .5gph 80° Solid Cone	25.5 KPa (3.7 psig)	No Atomization-Only Large Drops
101 KPa (14.7 psia)	Delavan 10 gph 80° Hollow Cone	25.5 KPa (3.7 psig)	Atomized Spray-Solid Cone Pattern
101 KPa (14.7 psia)	Delavan 10 gph 80° Solid Cone	25.5 KPa (3.7 psig)	Atomized Spray-Solid Pattern
101 KPa (14.7 psia)	Delavan LF 1 110° Flat Spray	25.5 KPa (3.7 psig)	Atomized Spray-Thin Fan Pattern
101 KPa (14.7 psia)	Hago .6gph 45° Hollow Cone	25.5 KPa (3.7 psig)	Continuous Drip
93 Pa (700µ)	Delavan 10 gph 80° Hollow Cone (nozzle 4" from flat grid plate)	25.5 KPa (3.7 psig)	Atomized cone of water .3-.5" from nozzle then spray turned to slushy ice
80 Pa (600µ)	Delavan LF1 110° Flat Spray (nozzle 8" from grid plate)	27.6 KPa (4 psia)	Inconsistant Pattern as Ice Built up in Slot on Nozzle

1) Griffen, E. and Muraszew, A. "The Atomization of Liquid Fuels" John Wiley and Sons, New York, 1953.
2) Tate, R. W. and Marshall, W. R. Jr. "Atomization by Centrifugal Pressure Nozzles" Chemical Engineering Progress, May, 1953.
3) Gaddis, J. L., French, R. J. and Esenwein, F. T., " "Feasibility Demonstration of a Spraying Flash Evaporator" Vought Missiles and Space Company Report No. 00.1427, May 7, 1971.

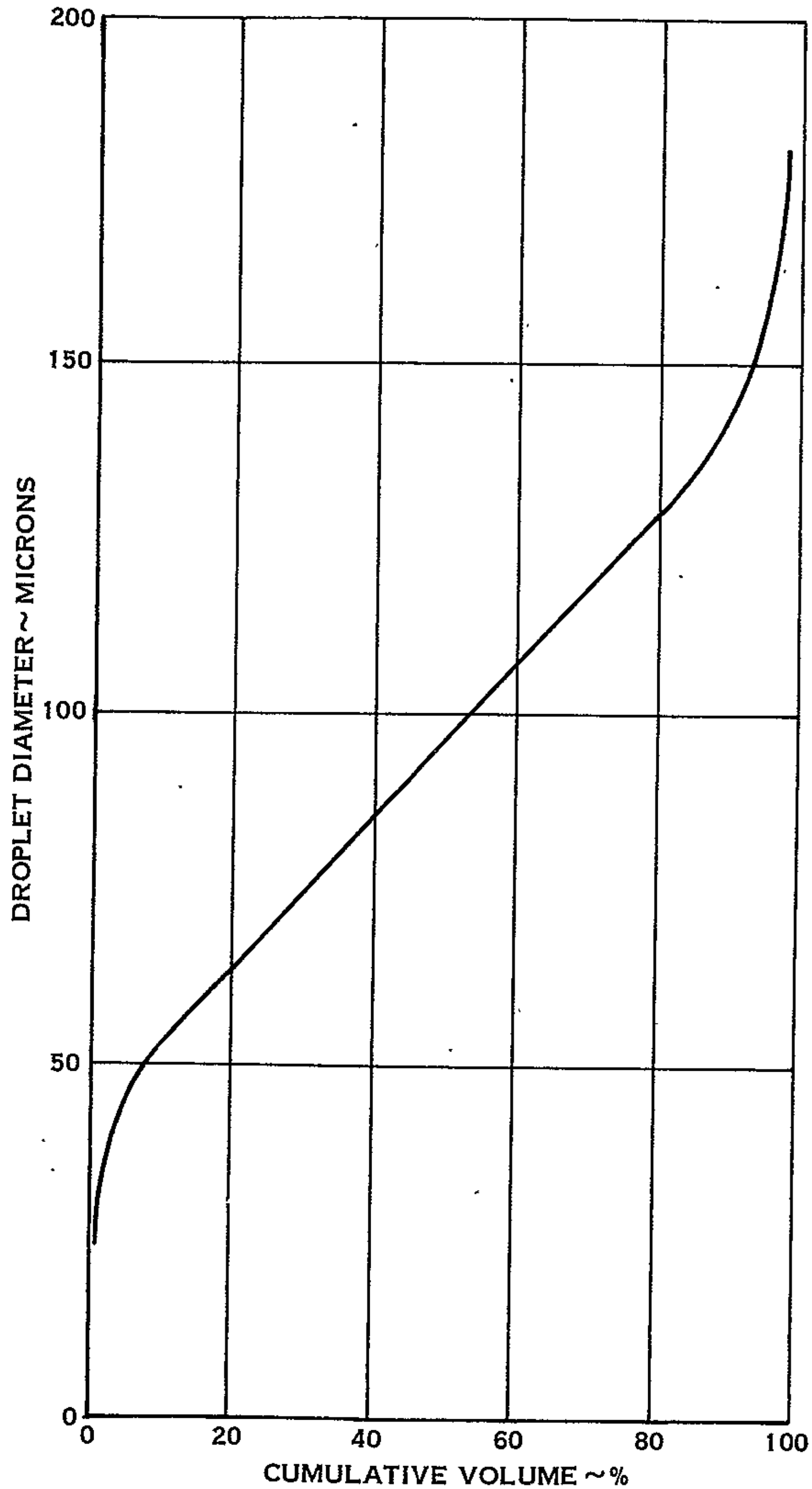


FIGURE D2 - 1. TYPICAL PRESSURE NOZZLE DROPLET DISTRIBUTION (REFERENCE 2)

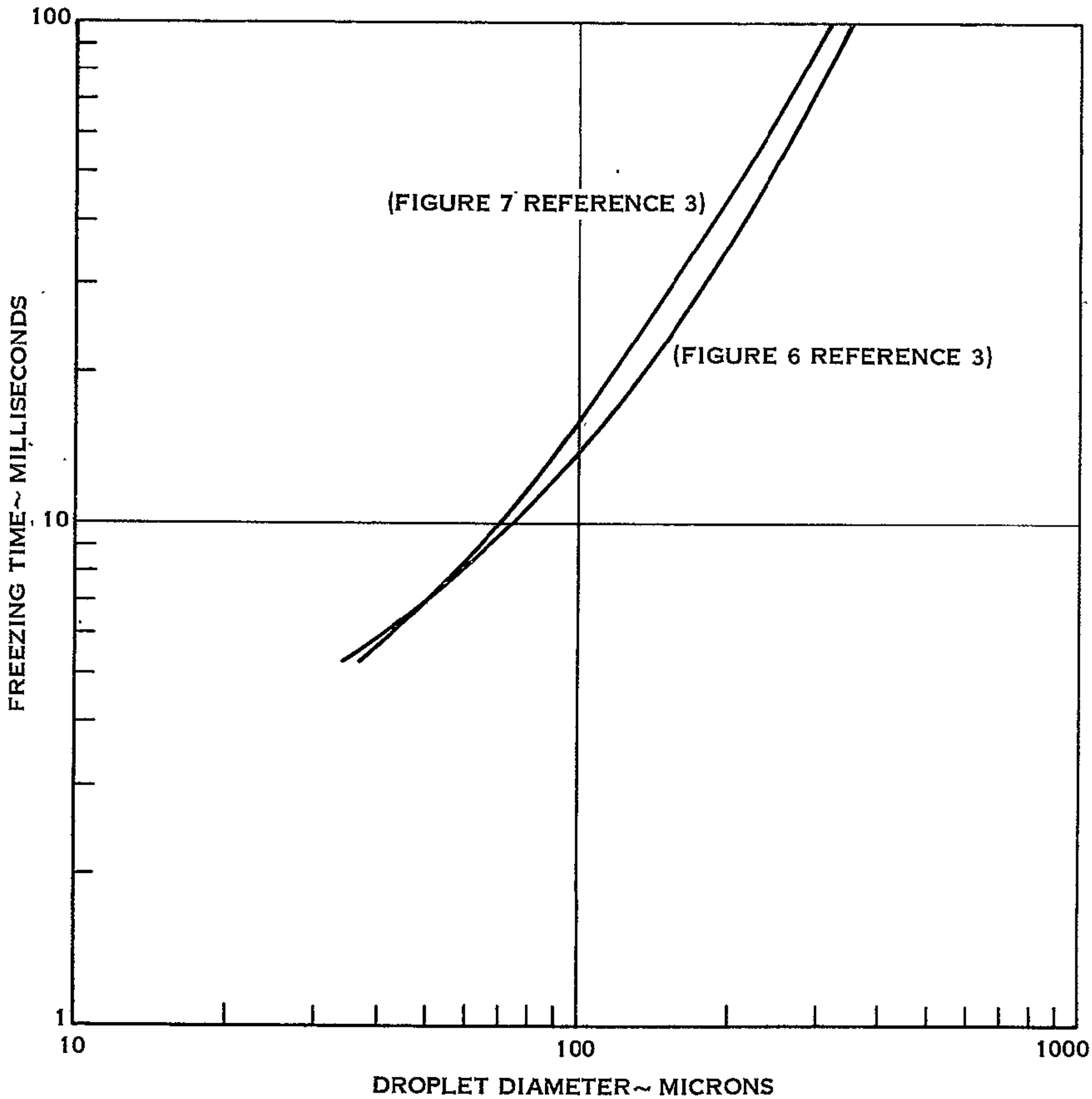


FIGURE D2 - 2. EFFECT OF DROPLET DIAMETER ON FREEZING TIME

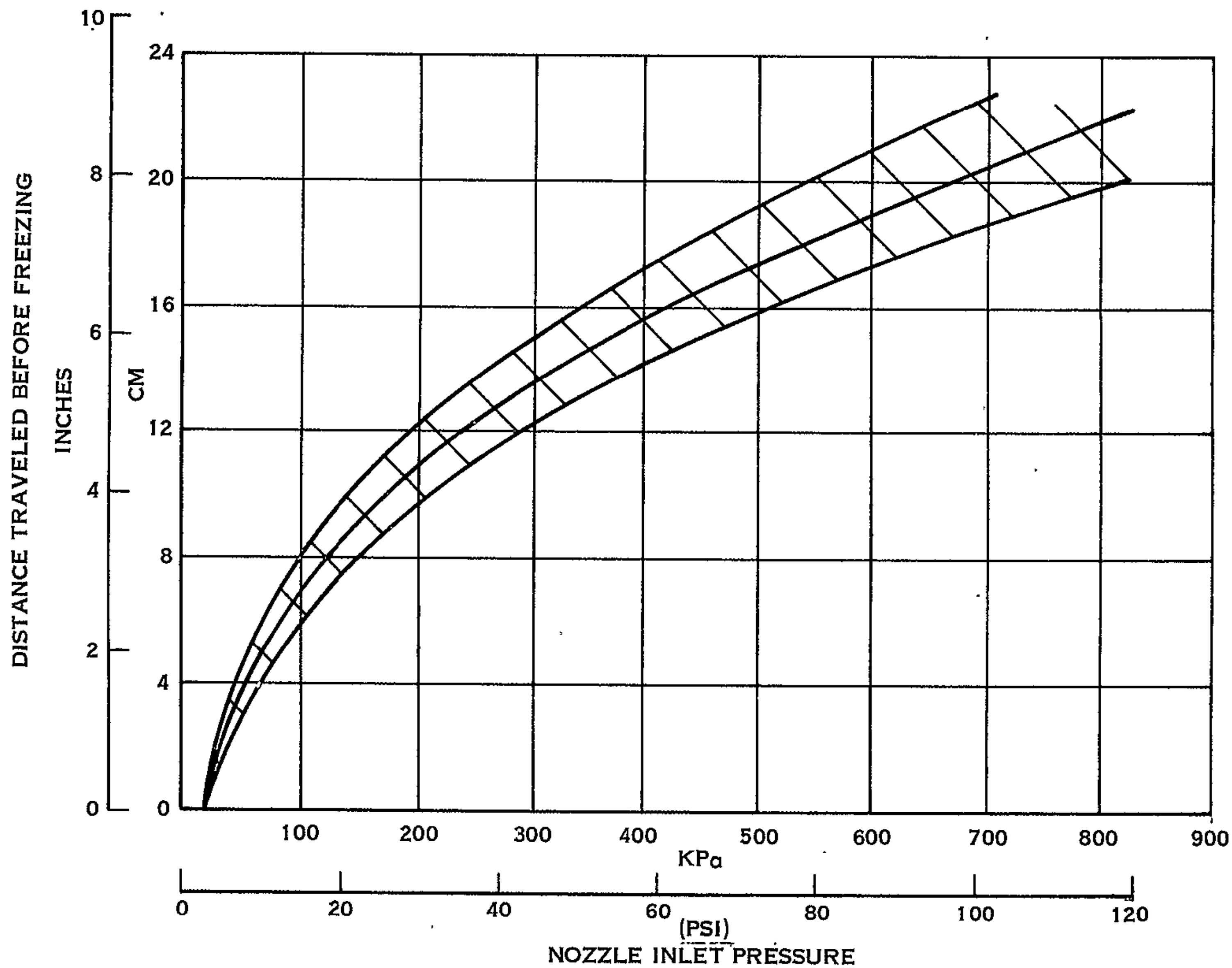


FIGURE D2-3. ESTIMATED FLOW LENGTH FOR 50 MICRON DROPLETS

APPENDIX E

HRS CONFIGURATION OPTIMIZATION

E-1.0 Introduction

The HRS candidate remaining after the preliminary screening consisted of the spraying flash evaporator utilizing either a hydraulic nozzle or a pneumatic nozzle and a replaceable plate sublimator. The configuration optimization study consisted of an evaluation of the two flash evaporator nozzles, various flash evaporator shapes and various heat exchanger combinations. This appendix contains a description of the candidates and the results of the evaluation.

E-2.0 Candidate Description

The ten candidates listed in Table E-2-1 were established for this study. The spraying flash evaporator with the hydraulic nozzle and pneumatic nozzle were previously described in Appendix C. Figure E-2-1 shows a cylindrical flash evaporator. Figures E-2-2, E-2-3 and E-2-4 depict the hexagonal, Flat plate and conical flash evaporators respectively. Each of these devices is a two fluid heat exchanger which would be used in conjunction with the stainless steel two fluid heat exchanger shown in Figure E-2-5 to form the two-two fluid heat exchanger arrangement. Figure E-2-6 shows how the cylindrical heat exchanger would be in a three fluid configuration.

This unit is larger than the two fluid device because the gas side thermal resistance sizes the heat exchanger. The same area is required for cooling the LCG but the heat exchanger must be made much larger in order to cool the vent loop.

Figure E-2-7 shows a two fluid sublimator that would be used in conjunction with the two fluid heat exchanger (Figure E-2-5) to form a two-two fluid heat exchanger arrangement. Figure E-2-8 shows the three fluid heat exchanger arrangement for the sublimator.

FLASH EVAPORATOR

NOZZLE TYPE

HYDRAULIC NOZZLE

PNEUMATIC NOZZLE

FLASH EVAPORATOR SHAPE

CYLINDRICAL

HEXAGONAL

FLAT PLATE

CONICAL

HX TYPE

THREE-FLUID HX

TWO TWO-FLUID HX

SUBLIMATOR

THREE-FLUID HX

TWO TWO-FLUID HX

TABLE E-2-1

HRS CONFIGURATION OPTIMIZATION CANDIDATES

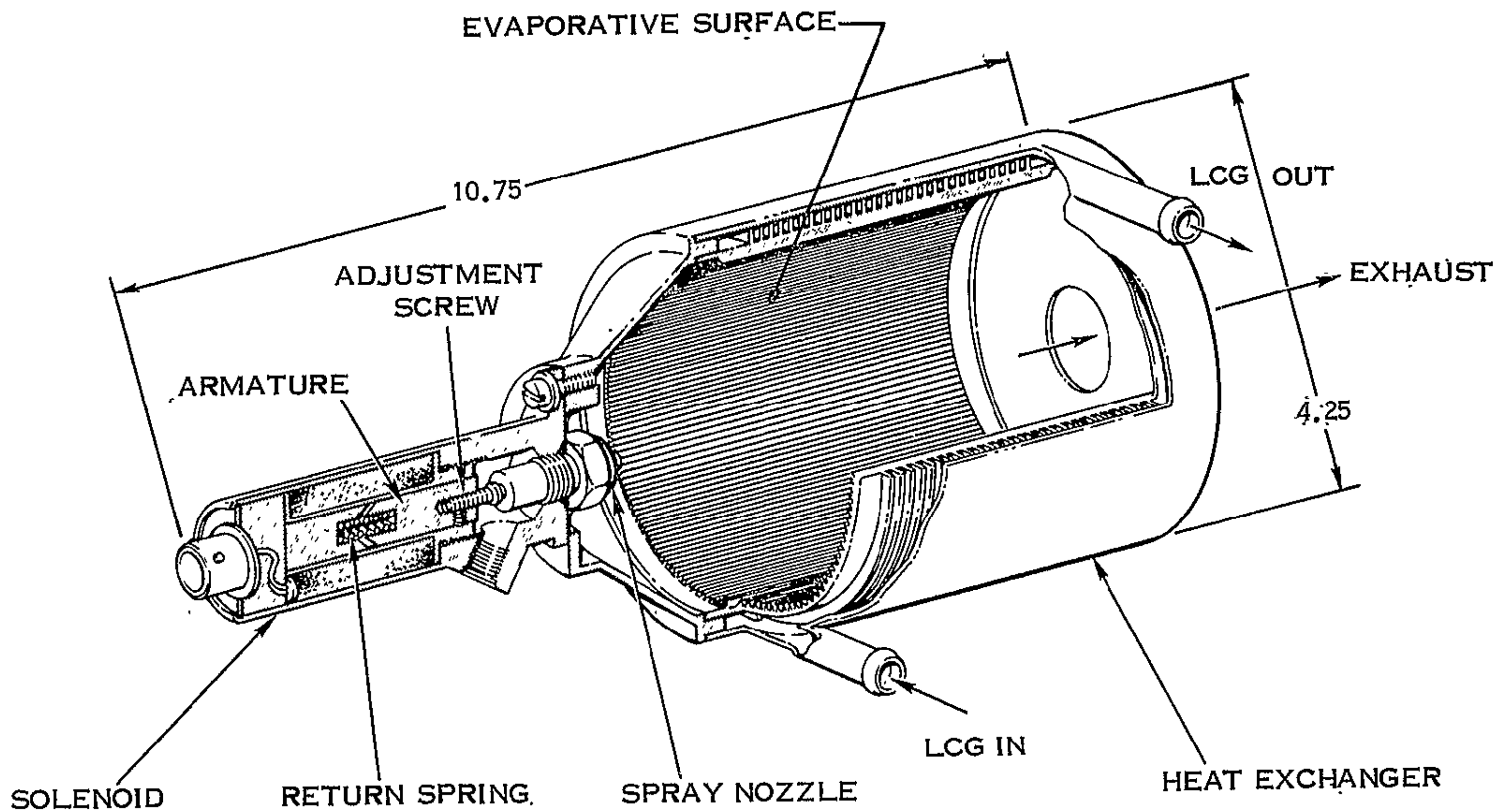


FIGURE E 2-1 SPRAYING FLASH EVAPORATOR WITH TWO FLUID HEAT EXCHANGERS

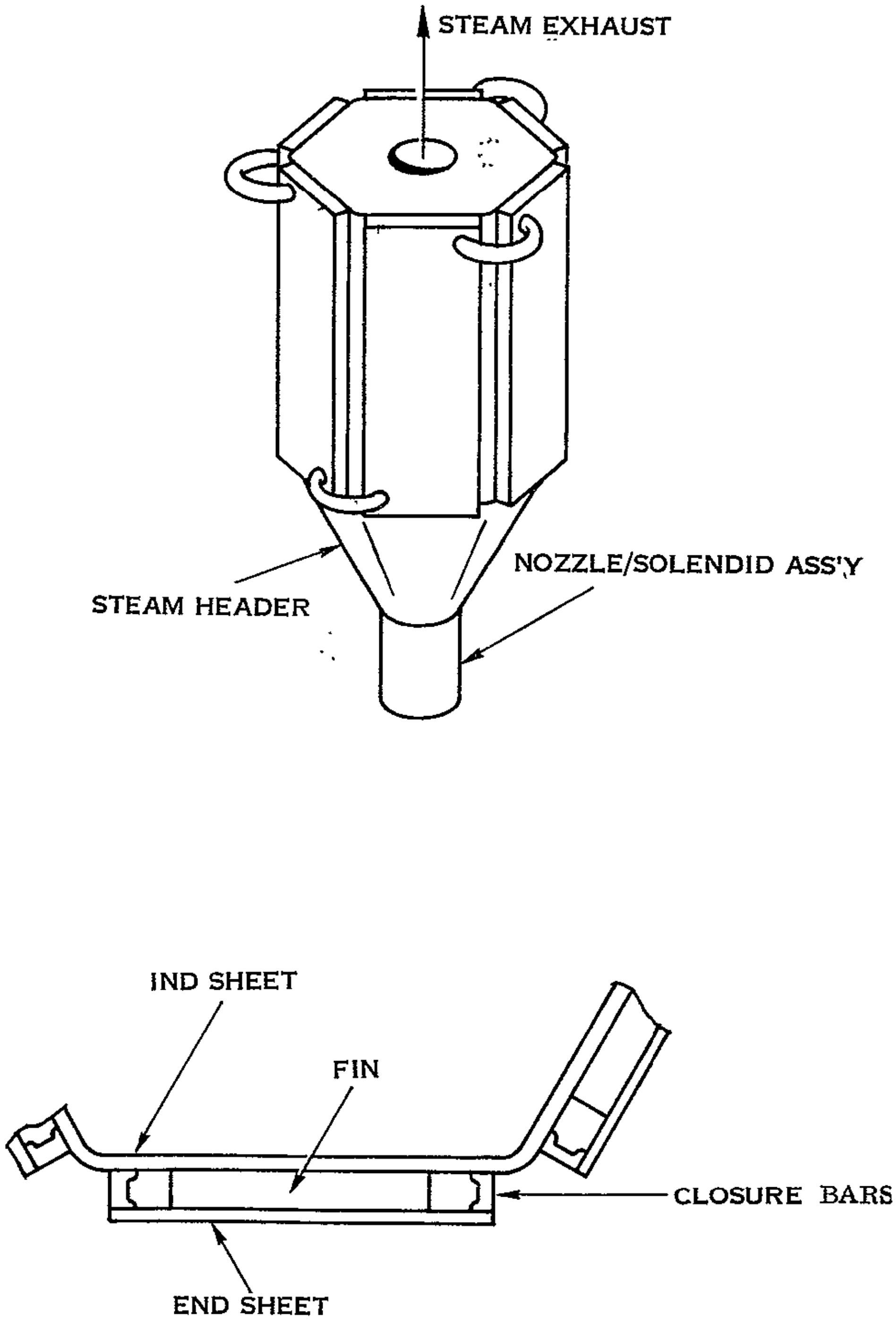


FIGURE E 2-2 HEXAGONAL FLASH EVAPORATOR

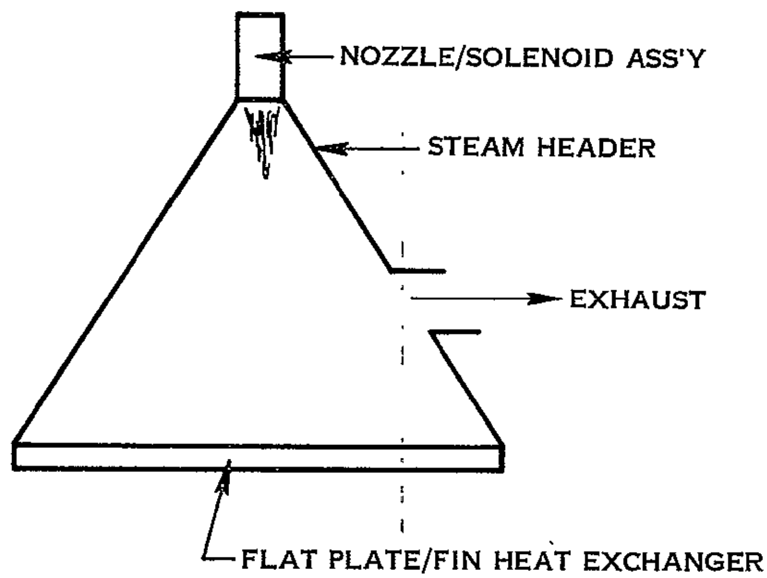


FIGURE E2-3 FLAT PLATE FLASH EVAPORATOR

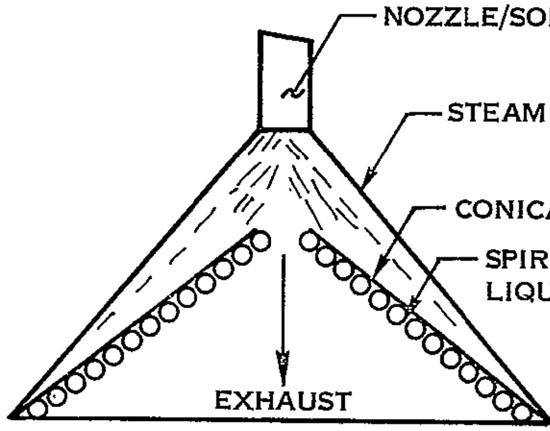
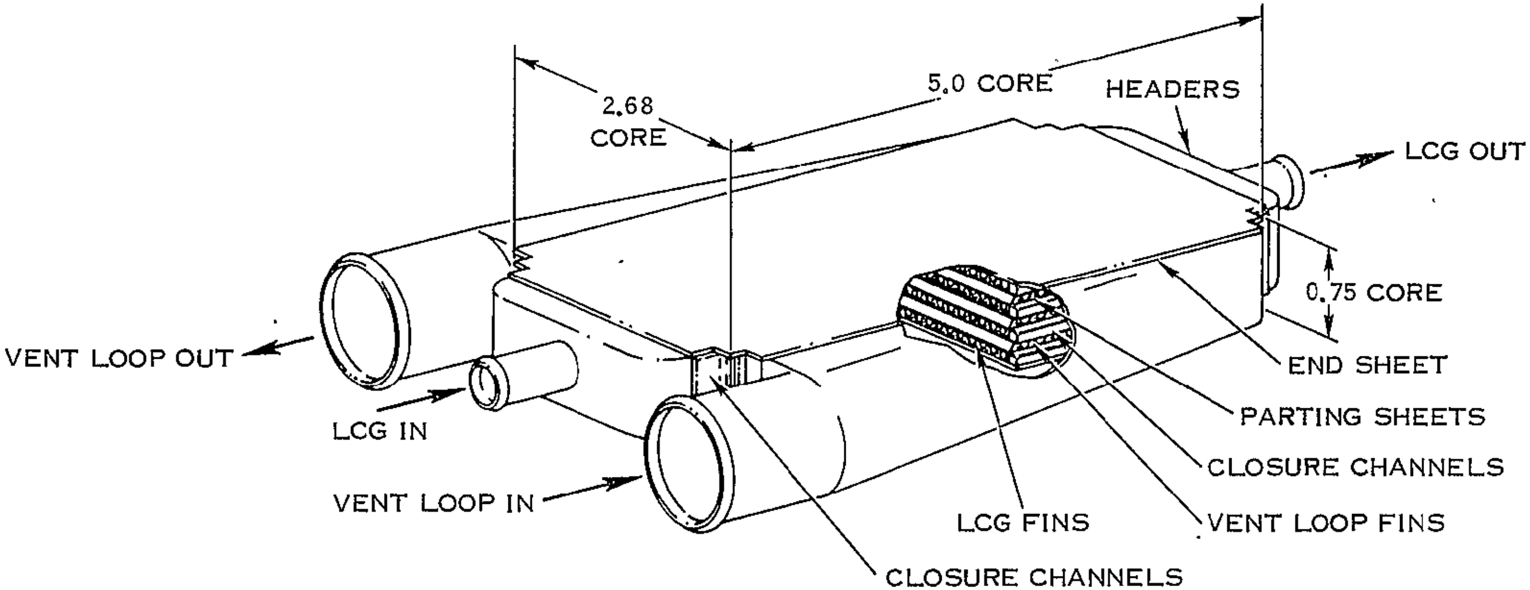


FIGURE E2-4 MINIMUM VOLUME CONICAL FLASH EVAPORATOR



TWO—FLUID STAINLESS STEEL HEAT EXCHANGER

FIGURE E-2-5

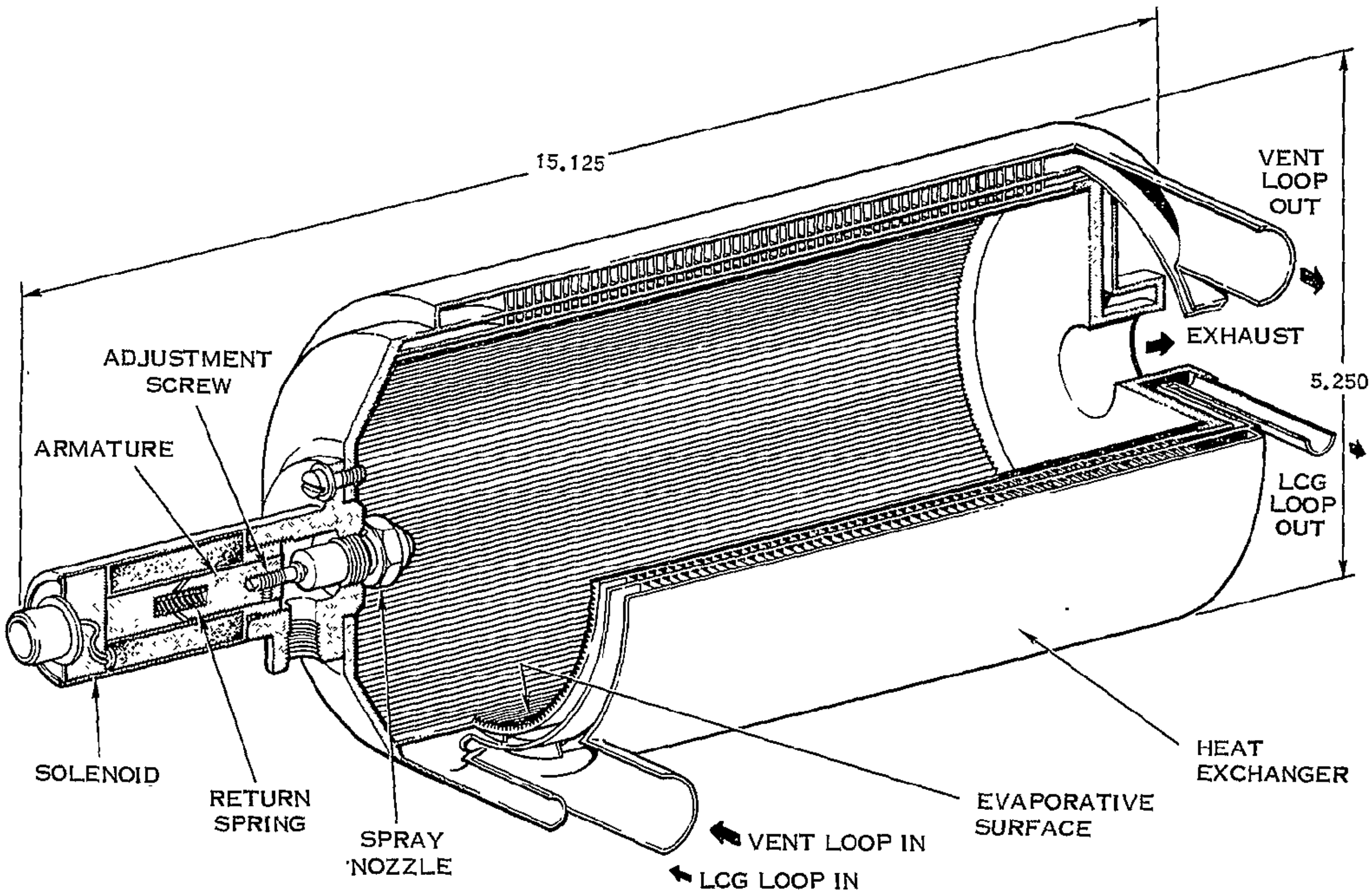


FIGURE E-2-6 THREE—FLUID FLASH EVAPORATOR

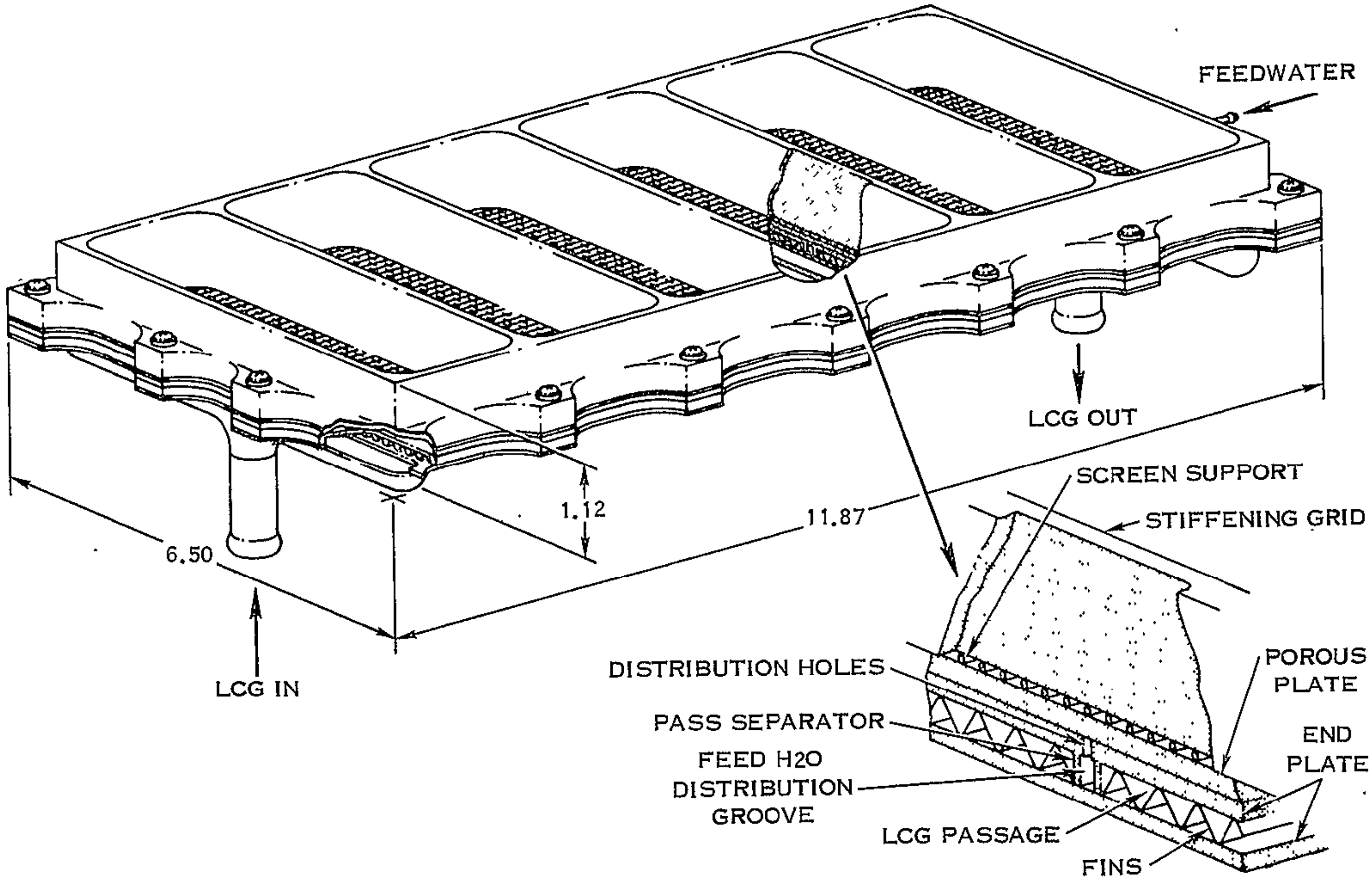


FIGURE E-2-7 TWO—FLUID ALUMINUM SUBLIMATOR

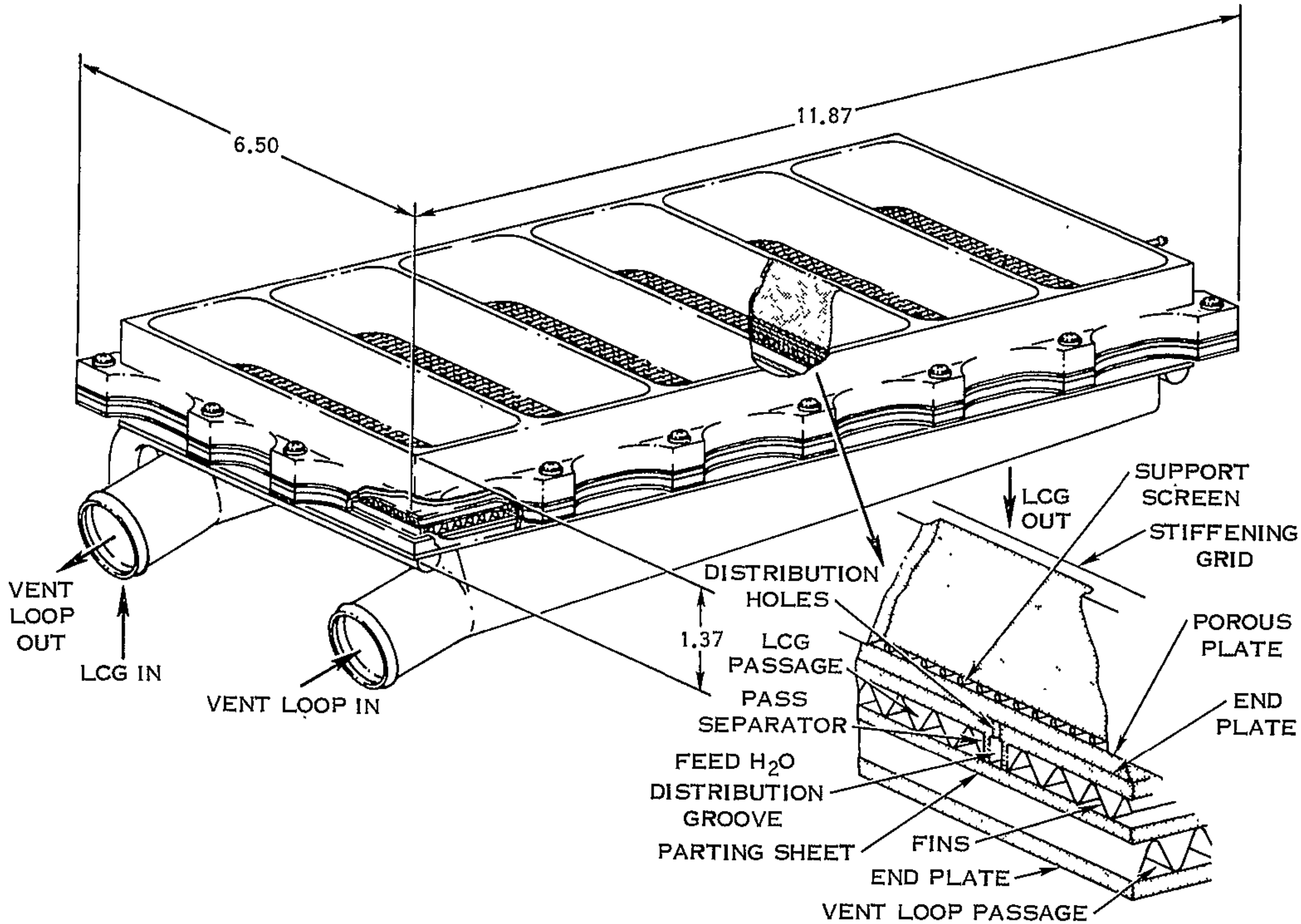


FIGURE E-2-8 THREE–FLUID ALUMINUM SUBLIMATOR

E-3.0 Evaluation

Because all the evaluation criteria were relative, it was necessary to conduct the evaluation between like items. Thus, in the case of the flash evaporator there was an evaluation of the nozzle type, heat exchanger type and of the heat exchanger shape while in the case of the sublimator, there was just a trade-off on the type of heat exchanger to use. The results of the evaluation are summarized in Table E-3-1 and are discussed in the following sections.

E-3.1 Flash Evaporator Nozzle Type

Both the hydraulic and pneumatic nozzles were considered competitive for life and hardware cost since both required the same number and types of components to assure proper operation. However, there is a significant weight and volume penalty for utilization of the pneumatic nozzle because of the necessity to store a large quantity of gas. This is reflected in Figure E-3-1. The hydraulic nozzle was selected because of its weight and volume advantage.

E-3.2 Flash Evaporator Shape

All four shapes were considered to have comparable lives and, as shown in Figure E-3-2, comparables weights. The flat flash evaporator was considered to be non-competitive from a volume standpoint since the unit had to have more surface area because of poor expandable water flow to the corners and because the shape of the device would not fit in a reasonable envelope. The remaining three shapes were considered to have similar volumes as shown in Figure E-3-2.

The hexagonal and conical shapes were considered to be more expensive to produce than the cylindrical shape. The cylinder would be formed by a simple turning operation followed by brazing while the hexagonal device required brazing of individual cones followed by welding the corner together and then welding jumpers between each core. The conical device requires forming of a spiral tube followed by brazing which would require expensive tooling.

Since the cylindrical shape was competitive in all categories, it was selected for the flash evaporator.

E-3 Flash Evaporator Heat Exchanger Type

There was no identifyable difference in the life of the two-two fluid HX approach and the three fluid HX approach thus both were considered competitive.

E-3.3 (Continued)

The hardware costs of the two approaches were considered comparable since the braze tooling and development of the braze technique for the three fluid device would offset the cost of producing the relatively simple plate fin gas/ water heat exchanger.

As shown in Figure E-3-3, the three fluid device is not competitive. volumetrically because the addition of the vent loop to the outside of the cylinder requires over sizing to assure the heat transfer capabilities between the two circuits. This has a significant impact on volume because the cylinder has a much lower packaging efficiency then the rectangular heat exchanger shown in Figure E-2-5

E-3.4 Sublimator Heat Exchanger Type

In the case of the three fluid sublimator, the over-sizing of the unit to accommadate heat transfer between the vent loop and liquid loop has a less pronounced effect than in the case of the flash evaporator because the rectangular sublimator has a higher packaging efficiency then does the flash evaporator. So while Figure E-3-4 does show a slight volume advantage for the two-two fluid approach both approaches were considered competitive. The only factor with any significant identifyable advantage is hardware cost The three fluid sublimator requires a slightly more expensive housing but it requires only one brazing operation while the two-two fluid approach requires more than double the core assembly, braze and test effort resulting in a significant cost advantage for the three fluid approach. Thus it was selected as the most competitive sublimator configuration.

TABLE E-3-1
HRS OPTIMIZATION CONCEPTS EVALUATION

Candidate	Life	Hardware Cost	EVLSS Weight	EVLSS Volume	Remarks
			(See Fig. E-3-1)	See Fig. E-3-1)	
Flash Evaporator					
. Nozzle Type					
Hydraulic	Competitive	Competitive	Competitive	Competitive	Selected Nozzle Type
Pneumatic	Competitive	Competitive	Not Competitive	Not Competitive	Reject
Flash Evaporator			(See Fig. E-3-2)	(See Fig. E-3-2-)	
. Shape					
Cylindrical	Competitive	Competitive	Competitive	Competitive	Selected Shape
Hexagonal	Competitive	Not Competitive More Costly than Cylindrical	Competitive	Competitive	Reject
Conical	Competitive	Not Competitive More Costly to Produce	Competitive	Competitive	Reject
Flat	Competitive	Competitive	Competitive	Not Competitive	Reject 8-1/2 Sq by 9.00 Long Does not fit in reasonable envelope

TABLE E-3-1 (Cont'd)

Candidate	Life	Hardware Cost	EVLSS Weight	EVLSS Volume	Remarks
			(See Fig. E-3-3)	(See Fig. E-3-3)	
Flash Evaporator					
. HX Type					
Three Fluid	Competitive	Competitive	Competitive	Not Competitive	Reject
Two-Two Fluid	Competitive	Competitive	Competitive	Competitive	Selected HX Type
Sublimator			(See Fig. E-3-4)	(See Fig. E-3-4)	
· HX Type					
Three Fluid	Competitive	Competitive	Competitive	Competitive	Selected Configu-ration
Two-Two Fluid	Competitive	Not Competitive (More Costly to produce two heat exchangers than one)	Competitive	Competitive	Reject

C-3

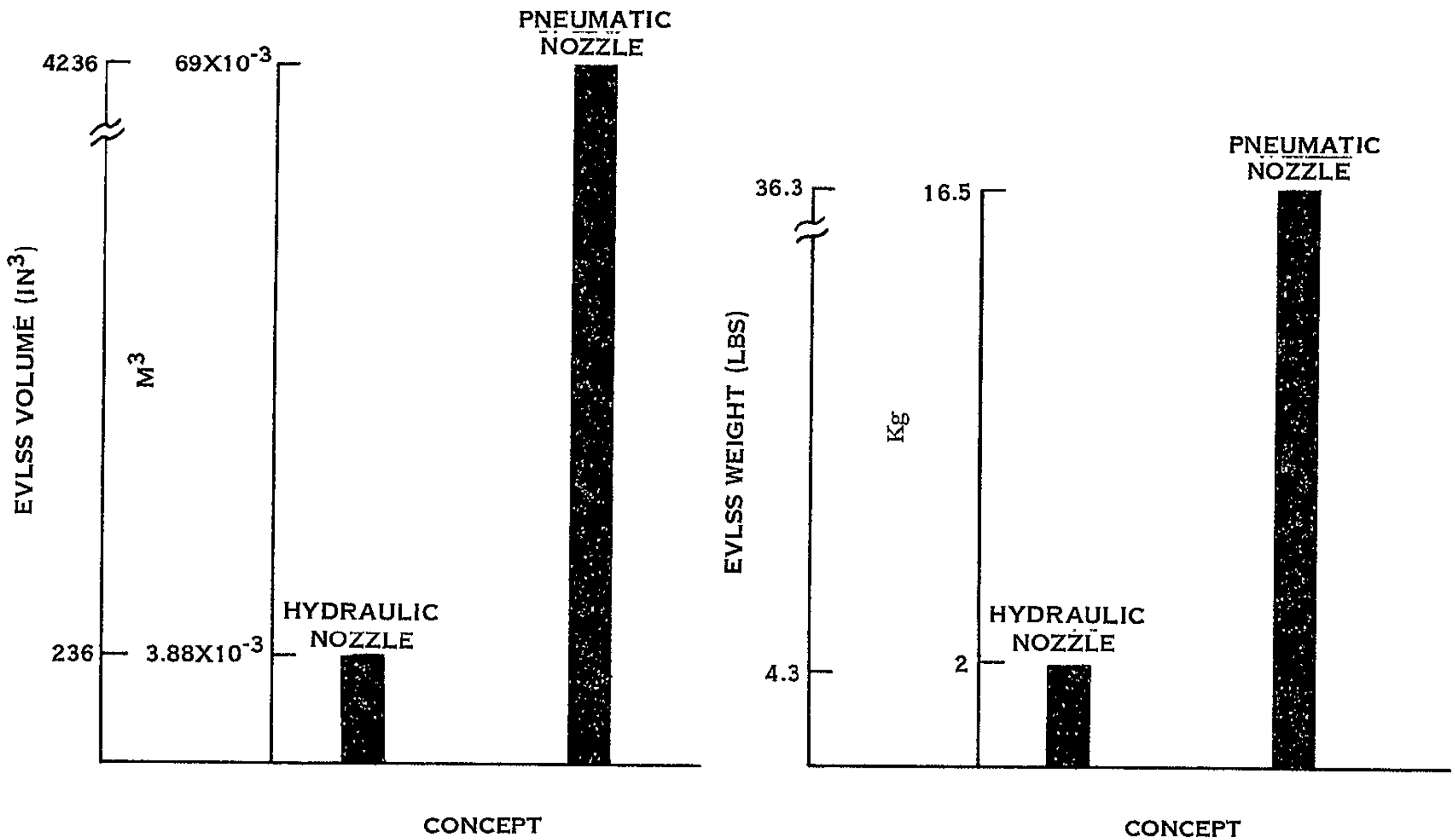
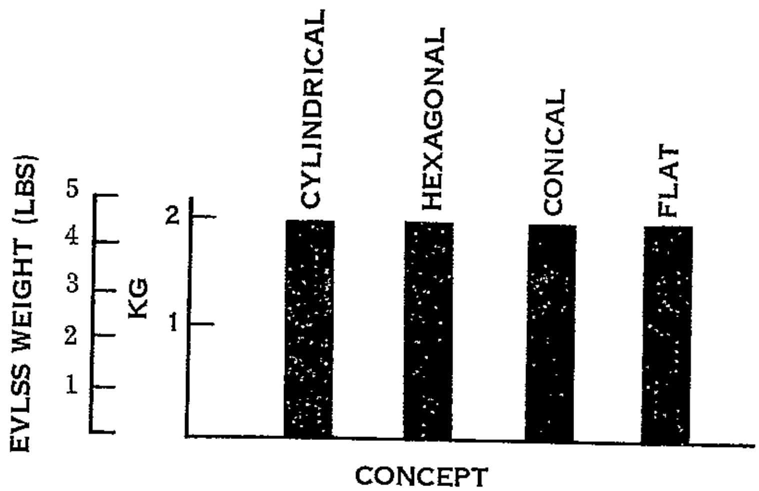


FIGURE E-3-1 FLASH EVAPORATOR NOZZLE WEIGHT AND VOLUME SUMMARY



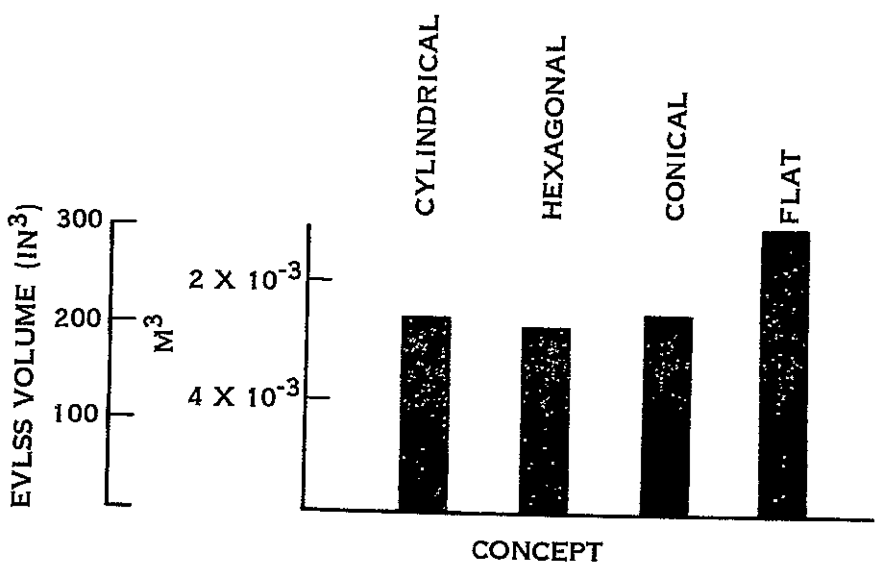


FIGURE E-3-2 WEIGHT AND VOLUME VS FLASH EVAPORATOR SHAPE

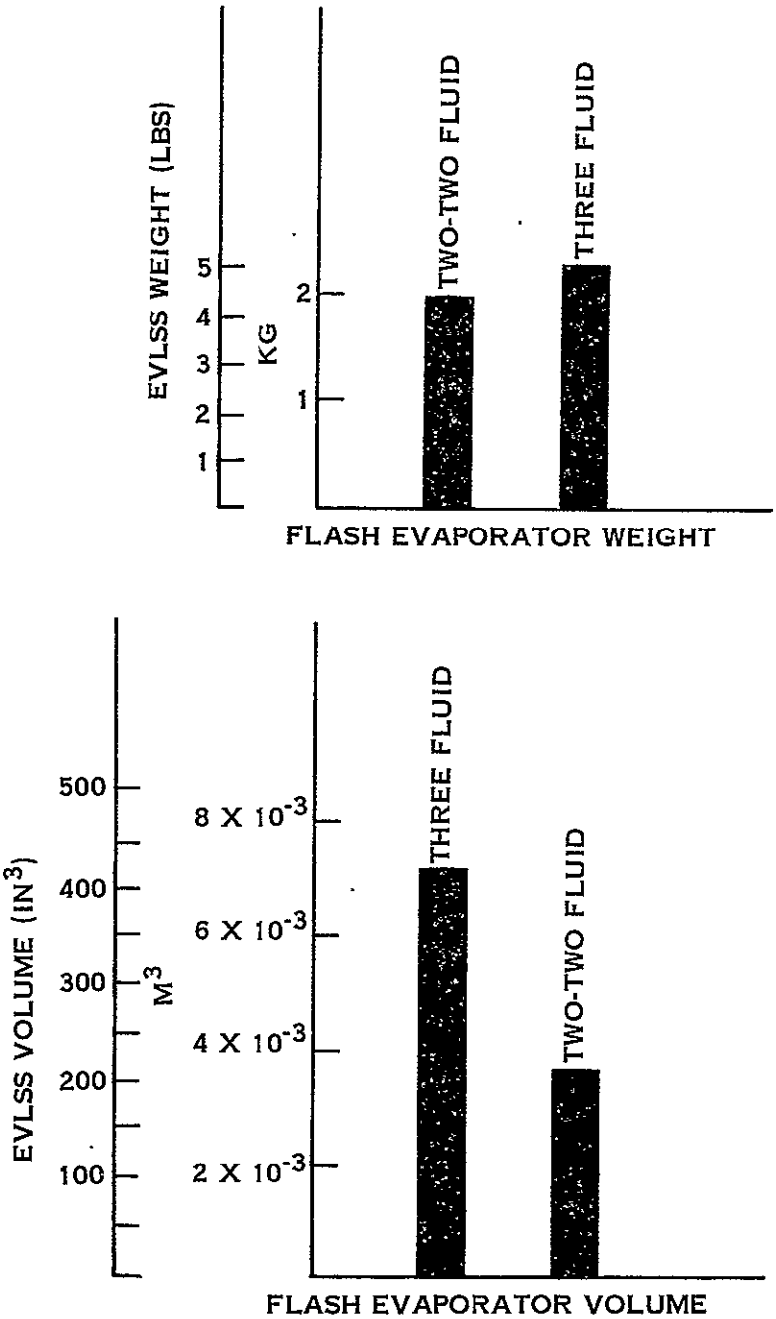


FIGURE E-3-3 WEIGHT AND VOLUME VS FLASH EVAPORATOR HX CONFIGURATION

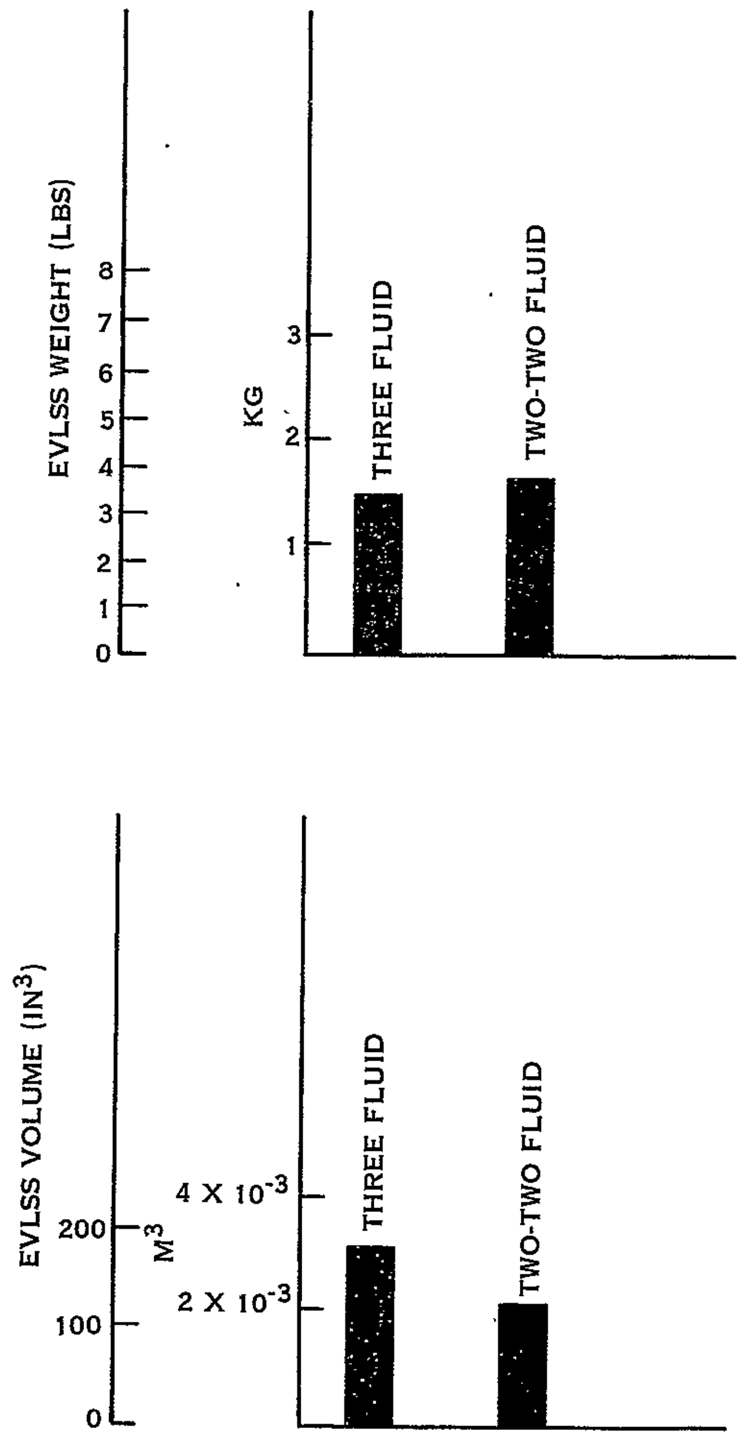


FIGURE E-3-4 WEIGHT & VOLUME VS SUBLIMATOR HX CONFIGURATION

APPENDIX F

WMS DEFINITION AND PRELIMINARY SCREENING

F1.0 INTRODUCTION

For the Water Management Subsystem evaluation, the 13 concepts listed in Table F1-1 were considered. Five of these concepts utilized a means of deaerating the water during charging, three utilized water that had been previously deaerated and five utilized the saturated water and contained provisions for it being saturated. This Appendix contains a description of the candidates and the results of the evaluation.

TABLE F1-1

WMS CANDIDATES

Concept Considered

- Hydrophylic/Hydrophobic Screen Separator
- Centrifugal Deaerator
- Permeation through Bladder
- Drive Gas out of Solution with Heat
- Bubble Expansion Tank
- High Pressure Storage
- Oversize Tank to Accommodate All Gas Evolved during Six Recharges
- Zero "G" Tank
- Scavenge Gas with Chemicals
- Bladder Storage with Water Pressure Regulator
- Replaceable H_2O Tanks
- Obtain Water Upstream of Water Tank (And Check Valves to Vehicle between Fuel Cell and Tanks)
- Use Vehicle Sublimator Water

F2.0 CANDIDATE DESCRIPTION

F2.1 WMS with Hydrophobic/Hydrophilic Screens (Figure F2-1)

This concept utilizes hydrophobic and hydrophilic screens to isolate any bubbles since gravity is not available during Shuttle missions. As nitrogen saturated water from the Shuttle Orbiter system enters the WMS fill fitting, it is forced through an orifice which reduces the pressure and agitates the flow to enhance the removal of gas from solution. The water and free gas bubbles enter the hydrophilic screen tube which retains the gas and allows the water to enter the bladder. During the filling operation, the separated gas is vented to the vehicle Waste Management System. The hydrophobic tube prevents water to flow in the drain line until a large enough pressure difference (full tank) permits water breakthrough. The sight glass provides a visual verification that the venting operation is complete.

The above concept physically integrates the gas/liquid separator in the reservoir. A variation of this concept is shown in Figure F2-2 where the gas/liquid separator is physically separated from the reservoir to permit simplification of the reservoir design.

These concepts may only be used with WMS systems that operate at 101 KPa (14.7 psia) or above because that is the minimum deaeration level achievable using this concept.

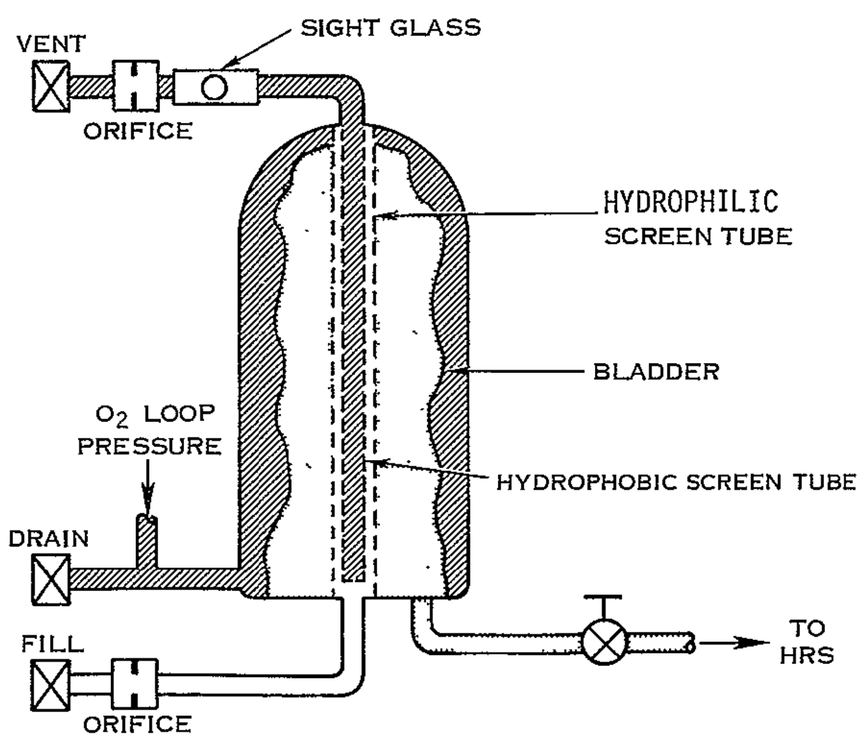
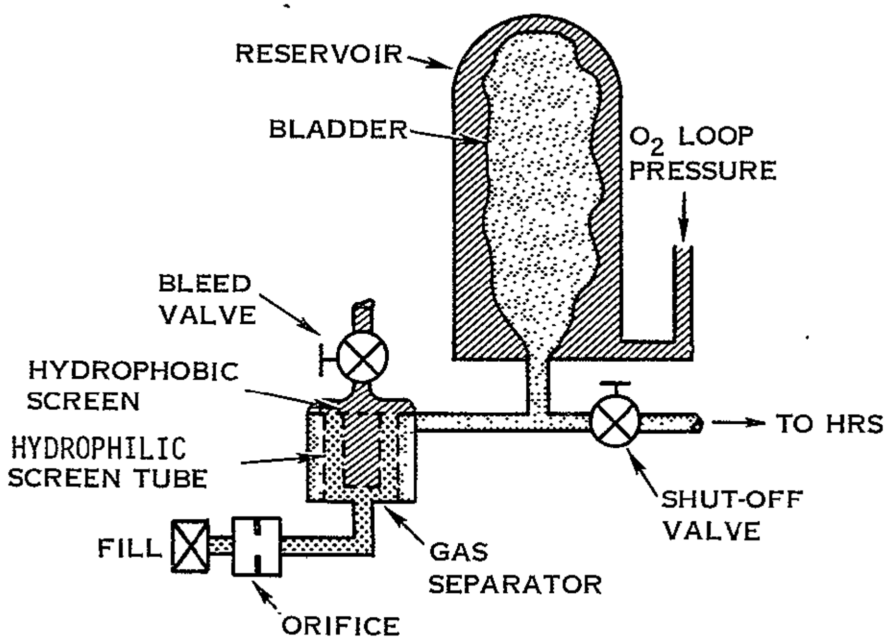


FIGURE F2-1
WMS WITH INTERNAL
HYDROPHOBIC/HYDROPHILIC SCREEN



WMS WITH EXTERNAL
HYDROPHOBIC/HYDROPHILIC SCREEN

F2.2 Centrifugal Deaerator (Figure F2-3)

The concept utilizes the rotating impeller to create the centrifugal field necessary under zero-g conditions to separate the gas from the water due to difference in the gas and liquid densities. The cone shape of the impeller ensures that the gas is always concentrated at the O_2 loop condensate line permitting evolved gases to be vented through the condensate line. The impeller also separates the condensate from the O_2 supply and mixes it with the feedwater for use as an expendable.

During filling, the rotating impeller permits the venting of all gases inside the reservoir through the drain fitting. A complete charge is indicated by the sight glass.

During start-up, the gas that comes out of solution as a result of decreasing the pressure to 26.8 KPa (3.85 psia) is vented back through the condensate line.

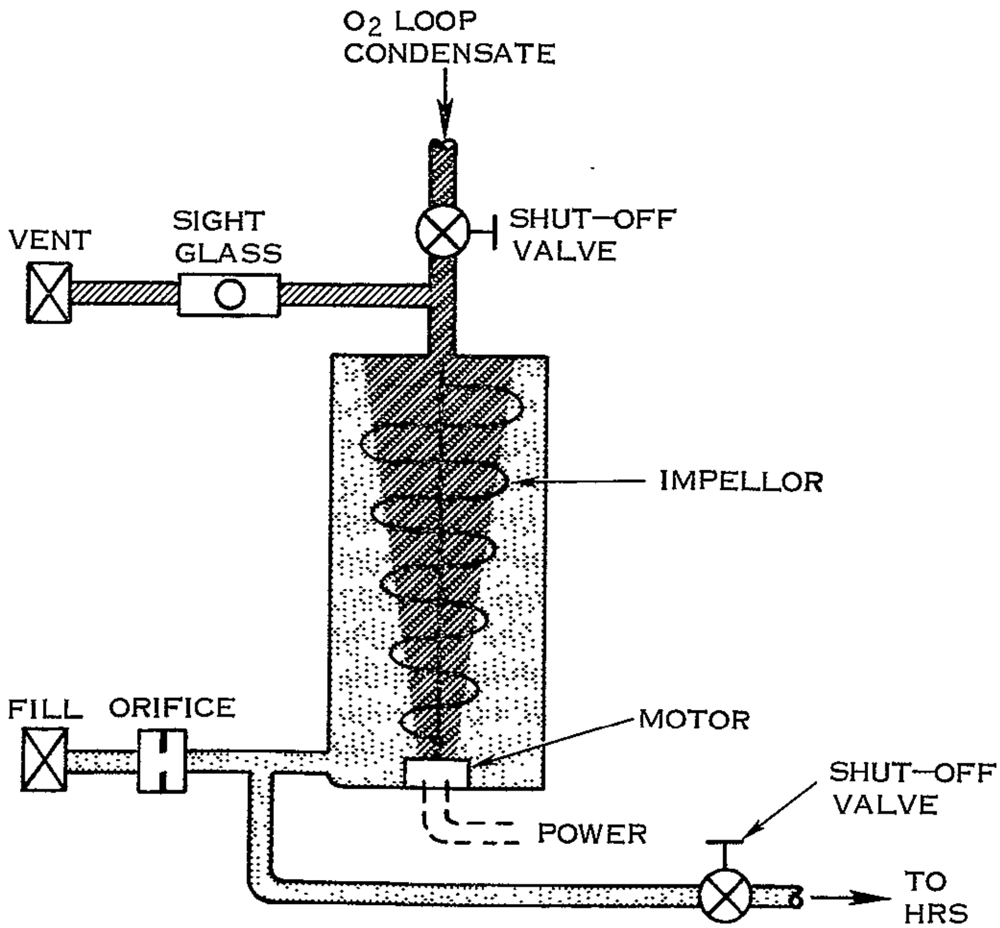


FIGURE F2-3
CENTRIFUGAL DEAERATOR

F2.3 Deaeration Through Bladder Permeation (Figure F2-4)

The vehicle water supply is saturated with gas because of high pressure gas (N_2) on the opposite side of a permeable bladder. Reversal of this mechanism is the basis of this concept which stores the saturated water within a permeable bladder. The opposite side of the bladder is exposed to near vacuum conditions to establish a pressure differential across the bladder to enhance gas permeation. With this concept, a vehicle supplied vacuum line is connected to the WMS after recharge and remains connected for a prescribed period of time.

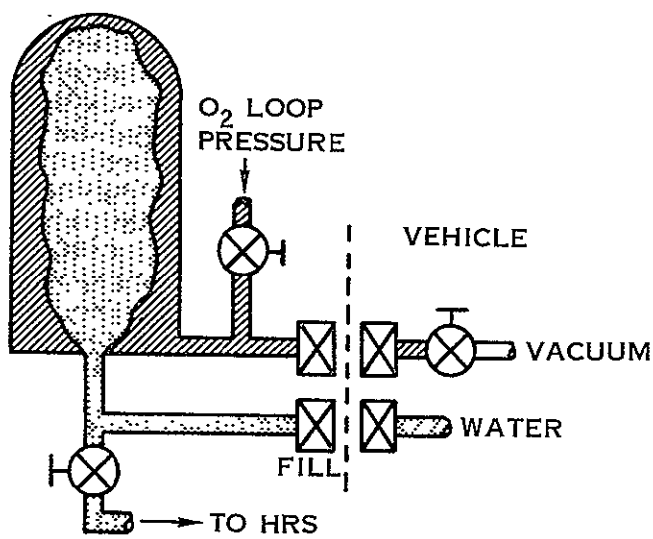


FIGURE F2-4
PERMEATION DEAERATION

F2.4 Deaeration Through Heating (Figure F2-5)

This concept utilizes the fact that the solubility of water decreases with increasing temperature. Figure F2-6 shows the solubility curves of water saturated with N_2 as a function of water temperature for water pressurized to 248 KPa (36 psia) (the fill pressure), 25.5 KPa (3.7 psia) (the EVLSS operating pressure) and 1 atmosphere, for comparison. There are three (3) operating temperatures to be considered.

a. 1.67°C (35°F) which is the minimum storage temperature.
b. 21.1°C (70°F) which is the approximate expected vehicle storage temperature.
c. 37.8°C (100°F) which is the maximum storage temperature.

It is desired to design this gas/liquid separator concept such that any residual gas remaining in the water after it is in the EVLSS WMS never comes out of

F2.4 Continued

solution, therefore, as seen in Figure F2-6, the 37.8°C (100°F) water storage temperature must be heated to approximately 90.6°C (195°F) while pressurized to 248 KPa (36 psia) driving the required amount of dissolved gas out of solution. A gas/liquid separator may remove this gas prior to cooling the liquid back to near the storage conditions.

The heat required to drive the fill water up to 90.6°C (195°F) can be minimized by the use of a regenerative heat exchanger which first preheats the water coming into the heater and then cools it back down after passing through the gas/liquid separator.

An effective regenerative heat exchanger permits the use of a small heater. Start-up may be accomplished by first turning on the heater until the water inside the heater reaches operating temperature, prior to initiating water flow.

A hydrophilic/hydrophobic screen separator continuously removes gas from the system as it is collected and it is vented to the cabin.

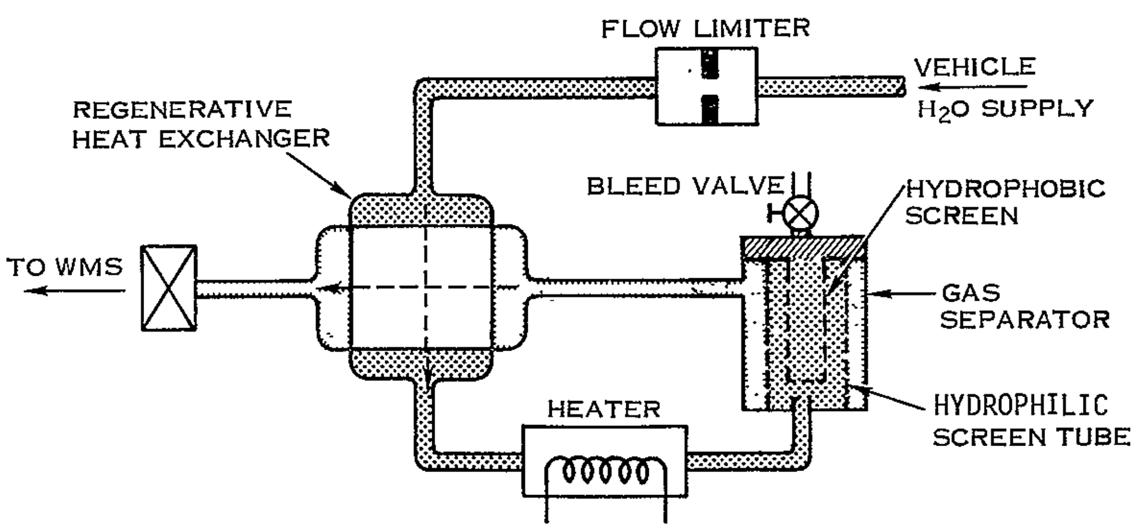


FIGURE F2-5
DEAERATION BY HEATING

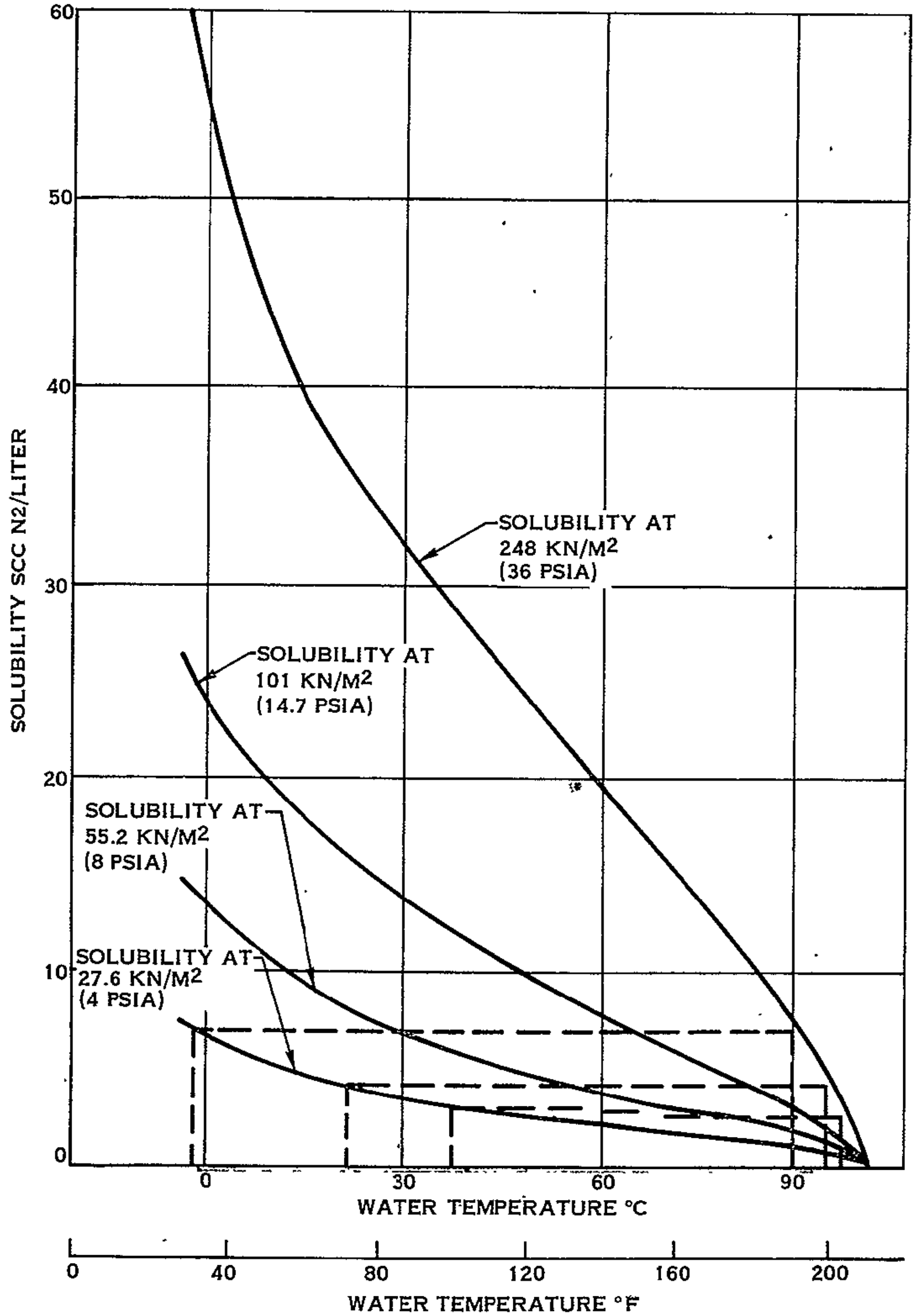


FIGURE F2-6. WATER SOLUBILITY-TEMPERATURE RELATIONSHIP

F2.5 Bubble Expansion Tank (Figure F2-7)

This concept represents an approach in which a WMS is designed to be compatible with gas saturated water which eliminates the procedures and equipment needed for water deaeration. Following the recharge sequence, the reservoir will contain water and gas bubbles pressurized to the same level as the vehicle water supply system.

The bubble expansion tank allows the gas to expand to the operating pressure of the WMS. For an 3.6 kg (8-pound) capacity primary tank, the expansion tank must be approximately 852 cc (52 cubic inches)(for an 27.6 KPa (4 psia) between the reservoir and the bladder and provides a constant regulated pressure for feedwater supply to the HRS.

Prior to recharging the reservoir, the water within the bladders of the reservoir and the bubble expansion tank are drained to the vehicle Waste Management System. This imposes no vehicle penalty since the Waste Management System already has the capacity to handle this water.

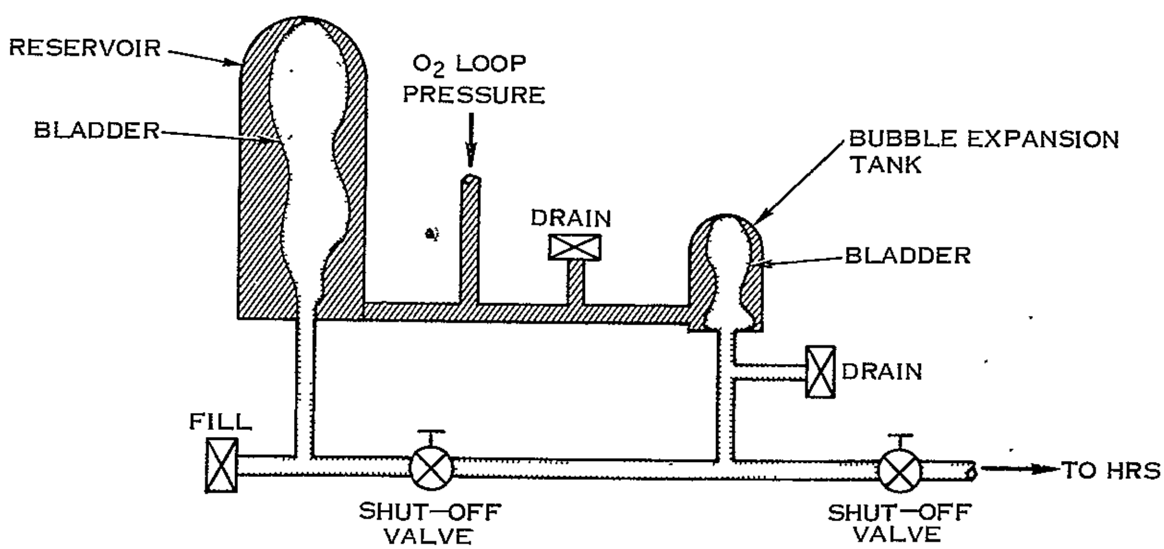


FIGURE F2-7
BUBBLE EXPANSION TANK

F2.6 High Pressure Water Storage (Figure F2-8)

This concept avoids the problem of having free gas in the reservoir by storing the water at a pressure above the vehicle fill pressure. During EVLSS

F2.6 Continued

recharge, a relief valve maintains the reservoir pressure slightly below the vehicle water supply pressure. This minimizes the quantity of gas evolving during the recharge sequence. A check valve in the fill line prevents the possibility of back flow.

During operation the EVLSS O_2 supply pressure source pressurizes the stored water above its saturation pressure (the vehicle supply pressure).

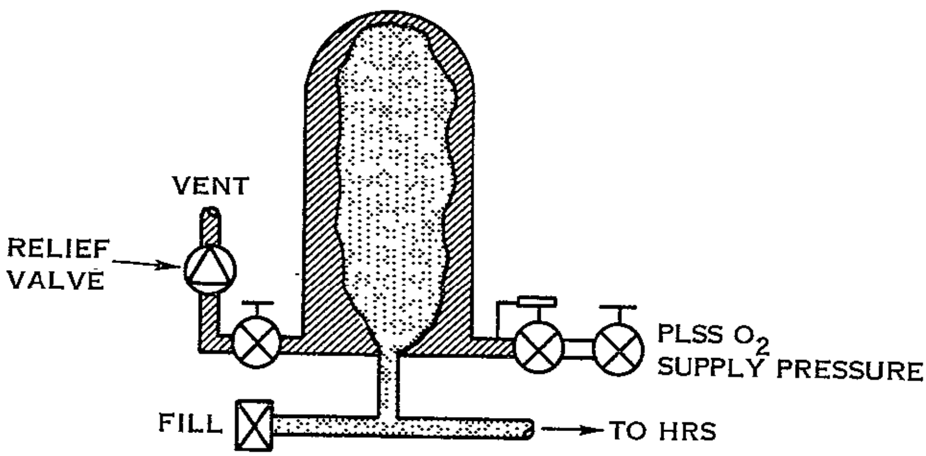


FIGURE F2-8
HIGH PRESSURE STORAGE

F2.7 Zero "G" Tank (Figure F2-9)

This concept utilizes the principal that in a zero-g environment a mixture of two fluids will seek to achieve a minimum energy state. Therefore, with an appropriately shaped storage vessel a liquid will try to attain a minimum surface tension by migration to the side of the tank having the smallest radius of curvature (for a hydrophyllic surface). At this side of the tank the water may be drawn off through a hydrophyllic screen to prevent the passage of gas. On the opposite end a hydrophobic screen permits the entry of O_2 plus condensate from the O_2 loop water separator. As the HRS draws water out of the tank there is created a Δ P across the hydrobic surface until breakthrough occurs forcing the condensate through the screen.. For filling, gas coming out of solution with the feedwater may be vented to the O_2 loop through the hydrobic screen.

F2.7 Continued

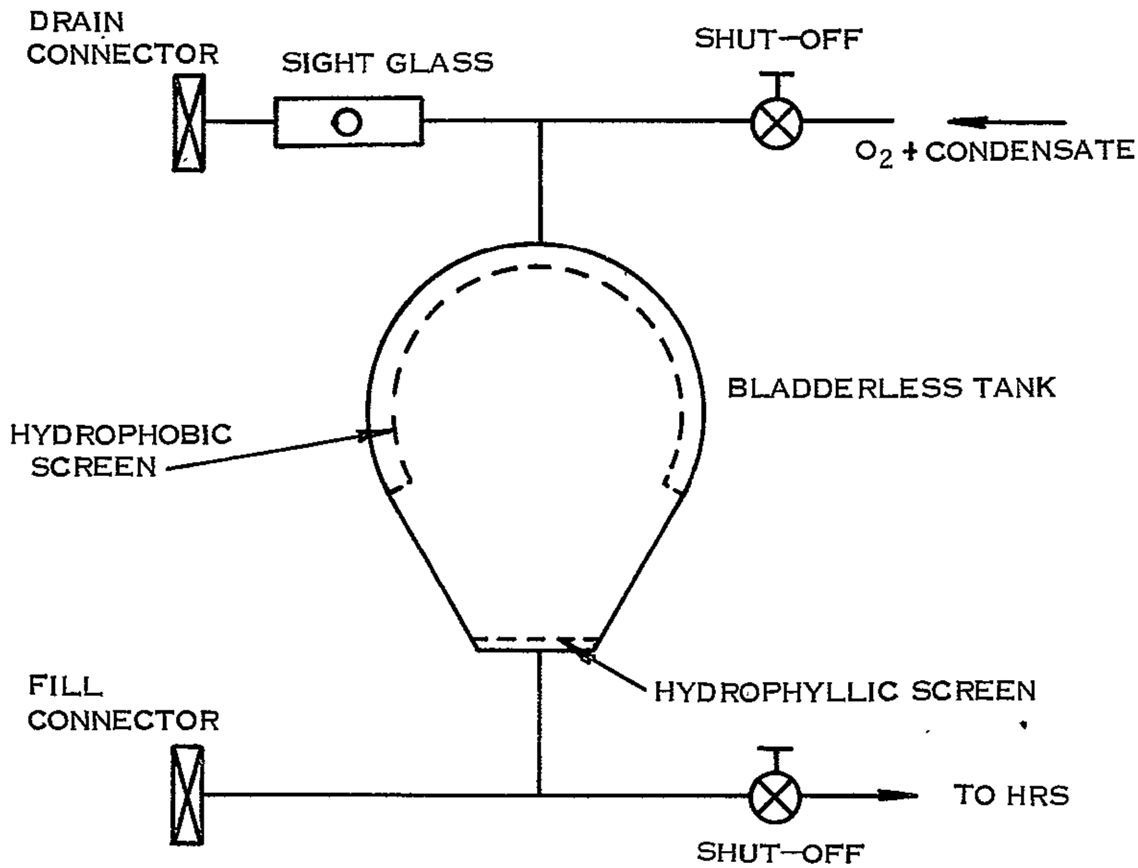


FIGURE F2-9
ZERO-G TANK

F2.8 Oversized Reservoir that Accommodates All Gas Released

This concept is the same as Bladder Storage with pressure regulator (Figure F2-10) except that the reservoir is sized to accommodate all of the gas released during six usages.

F2.9 Scavenging Gases with Chemical(s)

This concept is commonly used in the chemical process industries for removing dissolved gases from a liquid. A chemical is added to the liquid which combines with the dissolved gas forming a precipitate which then may be removed by filtration.

F2.10 Bladder Storage with Pressure Regulator (Figure F2-10)

In this system, the reservoir is charged with the saturated water. When the system is activated, the free gas in the water maintains the reservoir outlet pressure above 27.6 KPa (4 psi) for approximately the first hour of operation. The water regulators in the line to the HRS maintain the HRS inlet pressure at 27.6 KPa (4 psi) during this period of time. The water and gas remaining in the bladder after a mission is drained prior to recharge to minimize the reservoir size. This system is only compatible with the sublimator since the flash evaporator requires a pressure above 208 KPa (30 psi). There are redundant regulators to prevent full pressure on the sublimator in the event of a failed open regulator. If this over pressure protection is not provided, the sublimator support grid must be significantly oversized to maintain the proper feedwater gap at the higher pressure.

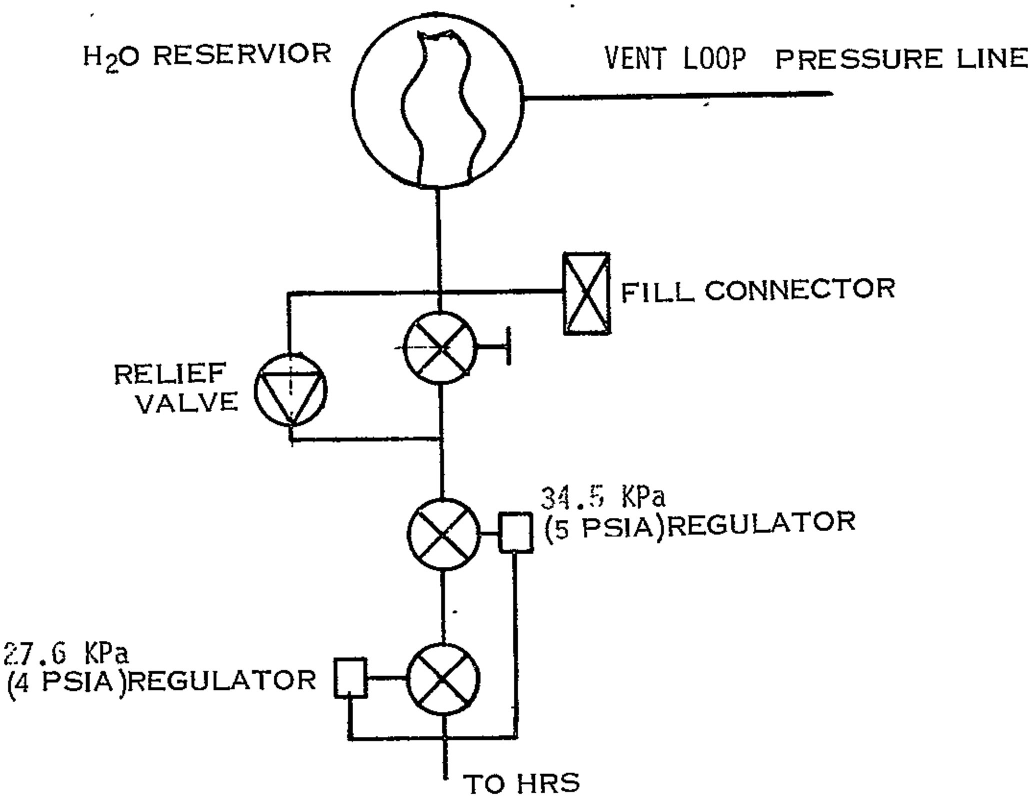


FIGURE F2-10
BLADDER STORAGE WITH PRESSURE REGULATOR

F2.11 Replaceable Water Tanks (Figure F2-11)

This concept eliminates the problem of handling saturated water by carrying charged canisters of water that are replaced after each EVA.

F2.11 Continued

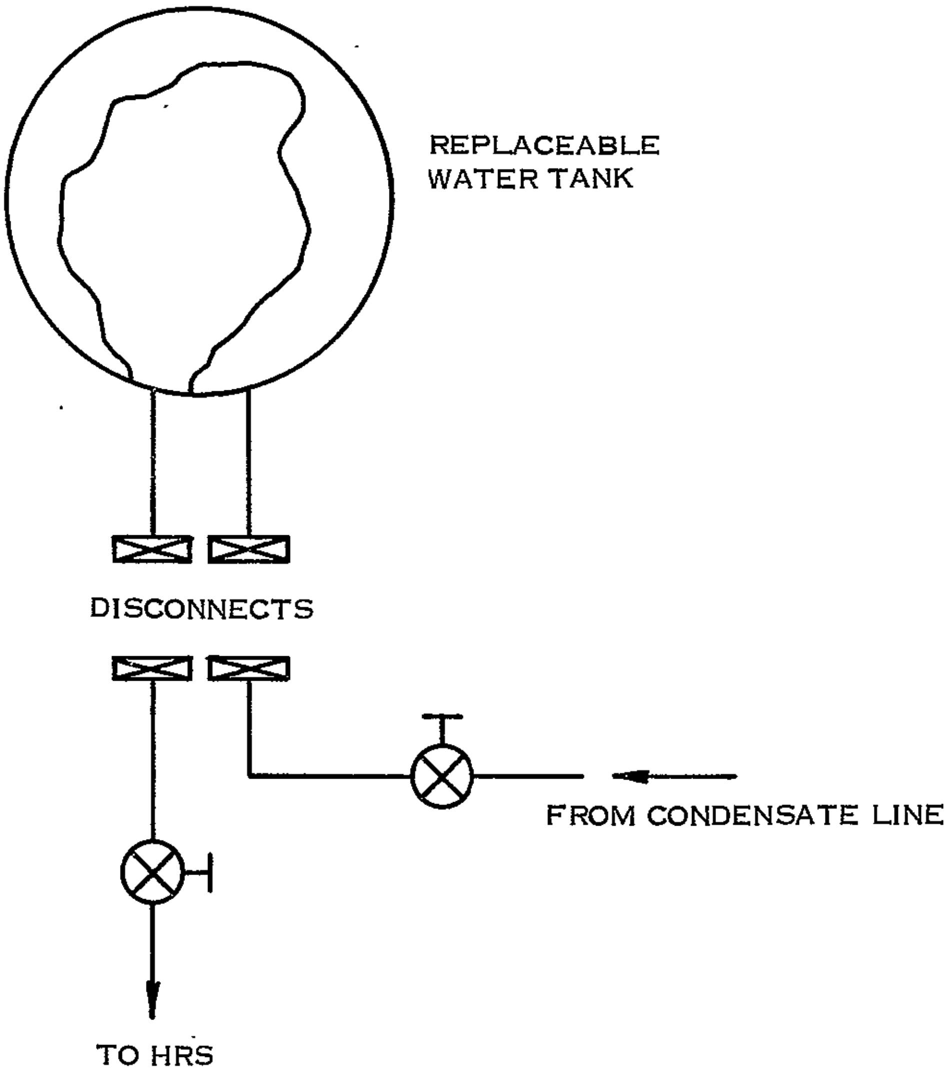


FIGURE F-211
REPLACEABLE WATER TANKS

F2.12 Obtaining the Water Upstream of the Vehicle Potable Water Tanks (Figure F2-12)

This concept eliminates the need to deaerate the water for use in the EVLSS because the water is obtained in a point in the vehicle water management system prior to being exposed to nitrogen gas. The water takes on N_2 gas in the vehicle potable water tanks by gas permeation through the bladders. A check valve between the potable water tanks and the point where the EVLSS draws water from the fuel cell supply prevents migration of N_2 gas to the EVLSS

F2.12 Continued

feedwater. A single check valve is required to satisfy the current Shuttle reliability philosophy. It should be noted that hydrogen is not a problem to the EVLSS because, downstream of the H_2 separator, the H_2 concentration is much below the saturation concentration equivalent to an operating pressure of 27.6 KPa (4 psia).

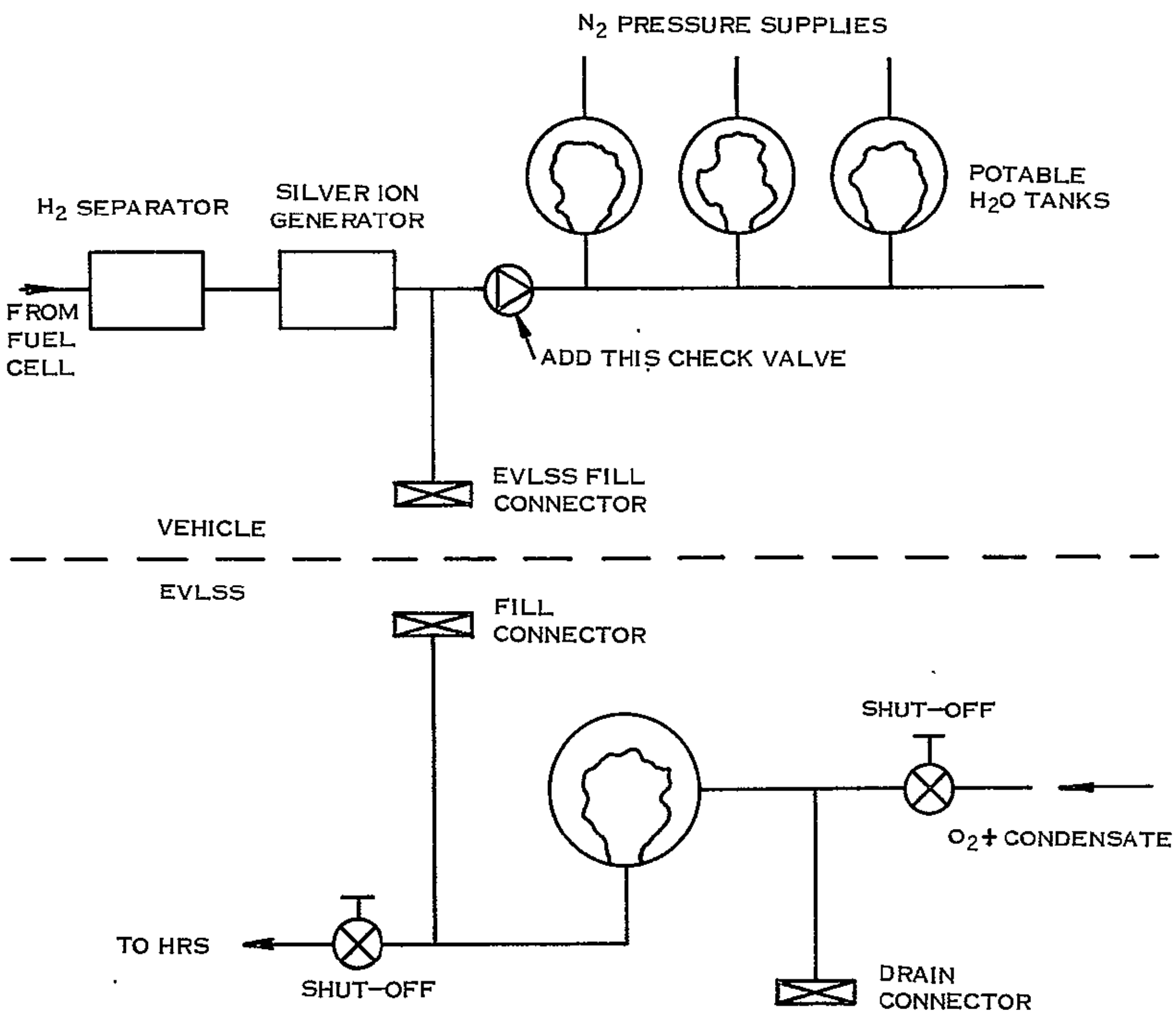


FIGURE 2-12
OBTAIN WATER UPSTREAM OF POTABLE WATER TANKS

F2.13 Use Vehicle Sublimator Feedwater (Figure F2-13)

This concept allows charging of this system with gas free water. The vehicle sublimator operates at 2-5 psia. Potable water is delivered to the sublimators via pressure regulators which drop the water pressure from 36 psia to the operating pressure. This concept uses the water immediately downstream of these regulators for EVLSS feedwater. However, the free gas in the water must be removed by the rotary separator prior to delivery to the EVLSS. The gas that is removed is vented to vacuum through the sublimators.

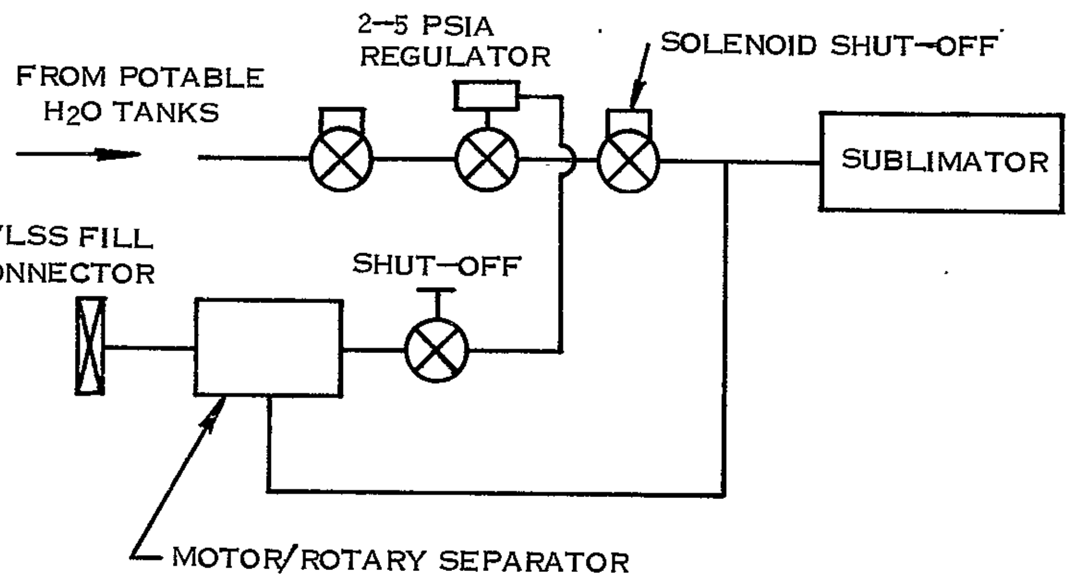


FIGURE F2-13
UTILIZATION OF VEHICLE SUBLIMATOR FEEDWATER

F3.0 CONCEPT EVALUATION

Each of the 13 concepts was evaluated to the two absolute criteria as summarized in Table F3-1. Those units found compliant were then evaluated against the relative criteria as summarized in Table F3-2.

TABLE F3-1

WMS PRELIMINARY SCREENING TO ABSOLUTE CRITERIA

Concept	Safety	Performance
Hydrophylic/Hydrophobic Screen Separator	Acceptable	Acceptable.
Centrifugal Deaerator	Acceptable	Reject: System is gravity sensitive and rotating mass of water could impart gyroscopic effects on astronaut interfering with mobility.
Permeatum through Bladder	Acceptable	Acceptable.
Drive Gas Out of Solution with Heat	Acceptable	Acceptable.
Bubble Expansion Tank	Acceptable	Acceptable.
High Pressure Storage	Acceptable	Acceptable.
Oversize Tank to Accommodate All Gas Evolved During Six Recharges	Acceptable	Acceptable.
Zero-G Tank	Acceptable	Reject: The acceleration forces produced when an astronaut moves are sufficient to overcome the surface tension forces which hold the water and gas in acceptable locations.
Scavenge Gas with Chemicals	Reject: Scavenging chemicals may be toxic.	Reject: The chemicals combine with the gas to form a precipitate which can plug filters or damage sealing surfaces.

F3.0 Continued

Concept	Safety	Performance
Bladder Storage with Pressure Regulator	Acceptable	Acceptable.
Replaceable H_2O Tanks	Acceptable	Reject: Non-compliant with specification requirement for recharge from vehicle.
Obtain Water Upstream of Potable Water Tank	Acceptable	Reject: Non-compliant with specification requirement for recharge with saturated water (feasible approach considered separately at TCS level).
Use Vehicle Sublimator Water	Acceptable	Reject: Non-compliant with specification for recharge with saturated water.

TABLE F3-2

WMS PRELIMINARY SCREENING TO RELATIVE CRITERIA

	Evaluation			
Concept	Development of Availability	Gross Vehicle Launch Weight	EVLSS Volume	Results
Hydrophylic/Hydrophobic Screen Separator	Competitive	(See Figure F3-1) Competitive	(See Figure F3-1) Competitive	Not considered further (see Note 1).
Permeation through Bladder	High risk since diffusion of air through water is difficult to predict. May require excessive charging time			Not considered further (high risk and see Note 1).
Drive Gas Out of Solution with Heat	Competitive	Not Competitive	Competitive	Not considered further (not weight competitive).
Bubble Expansion Tank	Competitive	Competitive	Competitive	Selected for further evaluation.
High Pressure Storage	Competitive	Competitive	Competitive	Selected for further evaluation.
Oversize Tank to Accommodate all Gas Evolved during Six Recharges	Competitive	Competitive	Competitive	Not considered further (see Note 1).

F3.0 Continued

Concept	Evaluation: Development of Availability	Evaluation: Gross Vehicle Launch Weight	Evaluation: EVLSS Volume	Results
Bladder Storage with Pressure Regulator	Competitive	Competitive	Competitive	Selected for further evaluation

Note 1: The hydrophylic/hydrophobic screen separator system, the permeation through the bladder system and the system with oversized tank are all slight modifications to the bladder storage with pressure regulator system. Each is somewhat more complex, heavier or larger than the basic system while offering no advantage thus, these concepts were not considered further.

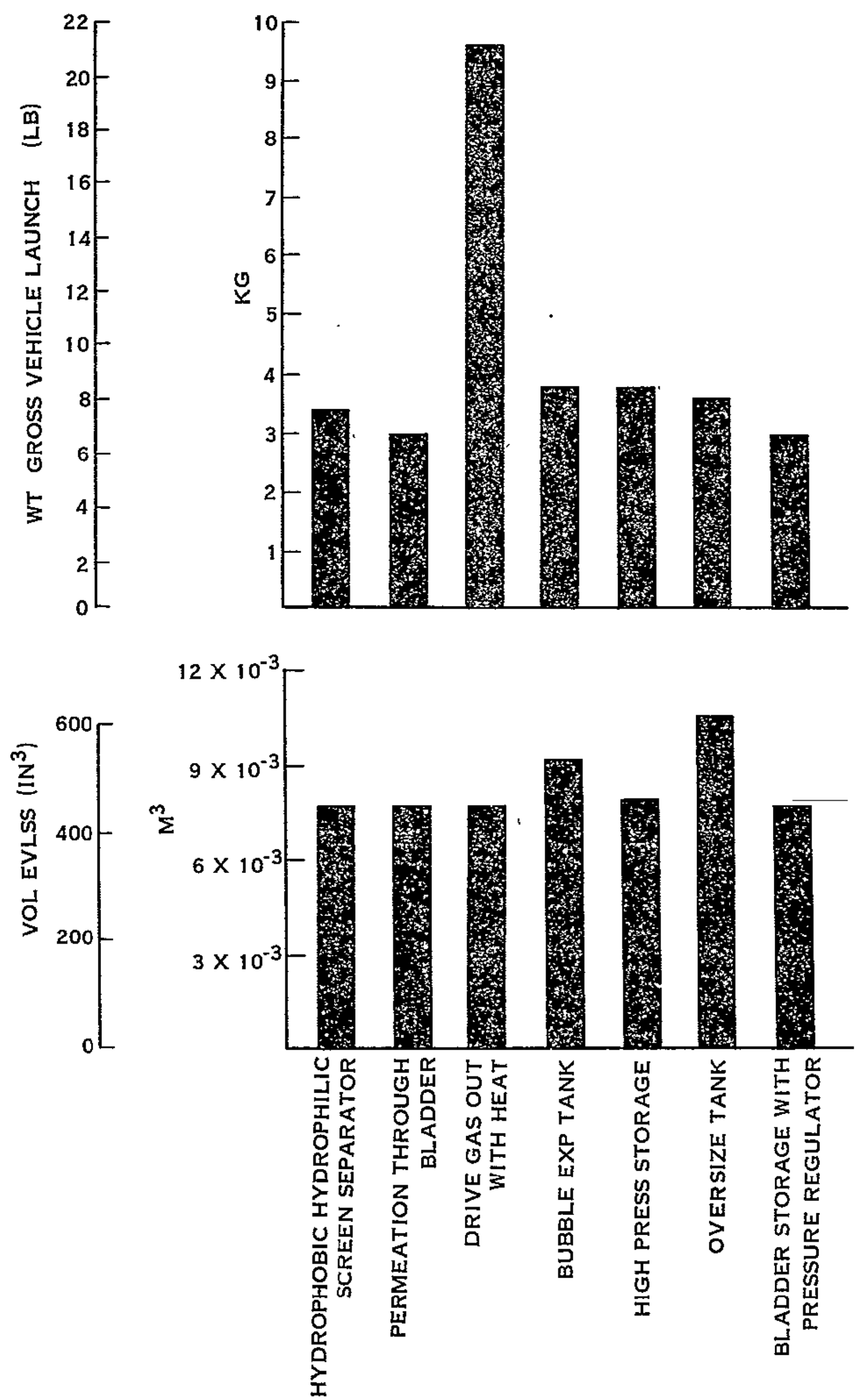


FIGURE F3 - 1. GROSS VEHICLE WEIGHT & EVCSS VOLUME VS WMS CONCEPT

APPENDIX G

WICK SEPARATOR MATERIAL TEST PROGRAM REPORT

G1.0 INTRODUCTION

This report describes the results of the Thermal Control System Wick Separator Material Test Program.

G2.0 PURPOSE

The purpose of the test program was to establish the performance characteristics of candidate wick materials with elastic recovery properties for use in a dischargeable wick separator.

G3.0 CONCLUSIONS

The Scott "Aquell" foam is the most suitable material of the materials tested for the wick separator application.

G4.0 DISCUSSION

The wick separator must separate the condensate from the secondary gas stream and store all of the condensate separated. It must be capable of being discharged at the end of each EVA. This requires the use of a material exhibiting elastic recovery properties, good wicking capability and high water storage capacity. A literature and industry search was conducted to define candidate materials. Eight manufacturers (Table G4-1) were contacted which resulted in selection of four candidate materials (see Table G4-2). These include two cellulose sponges, one natural ocean sponge and one hydrophilic polyurethane sponge. The two cellulose sponges (coarse and fine cell structure) were treated with platicizers and a fungicide by the supplier.

The test program was conducted to determine the following properties of each sample and to establish the most suitable material for the wick separator application:

Density
Wicking Height
Water Capacity
Volume Change
Water Retention After a Compression Cycle
Usable Water Capacity.

Since the design application required confinement of the material to prevent water blow by, a fixture that would confine the sponge on all sides except the upstream face was constructed (Figure G4-1) and used in each test except for the density test.

G4.0 Continued

The test results are summarized in Table G4-3 and the procedure used for each test is as follows:

Density

The density was equal to the actual sample weight divided by the actual sample volume.

Wicking Weight

The end of the fixture was placed in a dish of water with the sponge in contact with the water and the water level within the sample was allowed to stabilize. The difference between the height of the water within the sample and the water in the dish was the wicking height.

Water Capacity

The water capacity was determined by establishing the quantity of water retained by each sample. Each sample was covered with water (Figure G4-2) and then the shutoff valve was closed and the drain valve was opened. The samples were allowed to drip until all free water was eliminated after which each sample was weighed. The dry weight was subtracted from the wet weight and the resultant water weight versus the sample volume was the water capacity.

Volume Change

During the water capacity test, the height of the wick in the fixture when dry and when fully saturated was recorded. Since the wick could only grow in height, the ratio of the wet height to the dry height equalled the percent volume change.

Water Retention After a Compression Cycle

The fixture was fitted with a piston and the load on the piston was increased to obtain the desired test pressure (27.6 KPa [4 psid]). After the squeeze out, the sample was weighed. The squeeze out weight of the sample was subtracted from the wet weight and the resultant water weight versus the sample volume was the water retention after a compression cycle.

Usable Water Capacity

The usable water capacity was determined by subtracting the water retained after a compression cycle from the water capacity.

After these properties were determined, each sample was subjected to 10 wetting and drying cycles and then a 16-hour vacuum drying at 71°C (160°F).

G4.0 Continued

The weight and volume of each sample was determined and the percent difference from the initial values are included in Table G4-3.

The wicking height test was repeated and the results are also included in Table G4-3.

The natural sponge was found to have a negligible wicking capability and thus would be unsuitable for the separator application. Of the remaining samples, the Scott "Aquell" foam had the highest usable water capacity and thus would be the most suitable material for use in the dischargeable wick separator application.

TABLE G4-1

MANUFACTURERS CONTACTED

Approved Rubber Corp. 142 Lincoln Street Winthrop, Massachusetts	O-Cel-O General Mills Inc. Holzer Avenue Tonnawanda, New York
Durable Rubber Products Co. 1905 Mendell Street Chicato, Illinois	Pellon Corp. Industrial Div. 221 Jackson Avenue Lowell, Massachusetts
American Rubber & Plastics Co. 1941 Peter Street Laporte, Indiana	American Sponge & Chamois Co. Inc. 47-00 34th Street Long Island City, New York
B. F. Goodrich Sponge Product Div. 333 Derby Place Shelton, Connecticut	Foam Div. Scott Paper Co. 1500 East 2nd Street Chester, Pennsylvania

TABLE G4-2

CANDIDATE TEST MATERIALS

Material	Supplier
Scott "Aquell" Polyurethane	Foam Div. Scott Paper Co. 1500 East 2nd Street Chester, Pennsylvania
Super Cel #85 Cellulose	American Sponge & Chamois Co. Inc. 47-00 34th Street Long Island City, New York

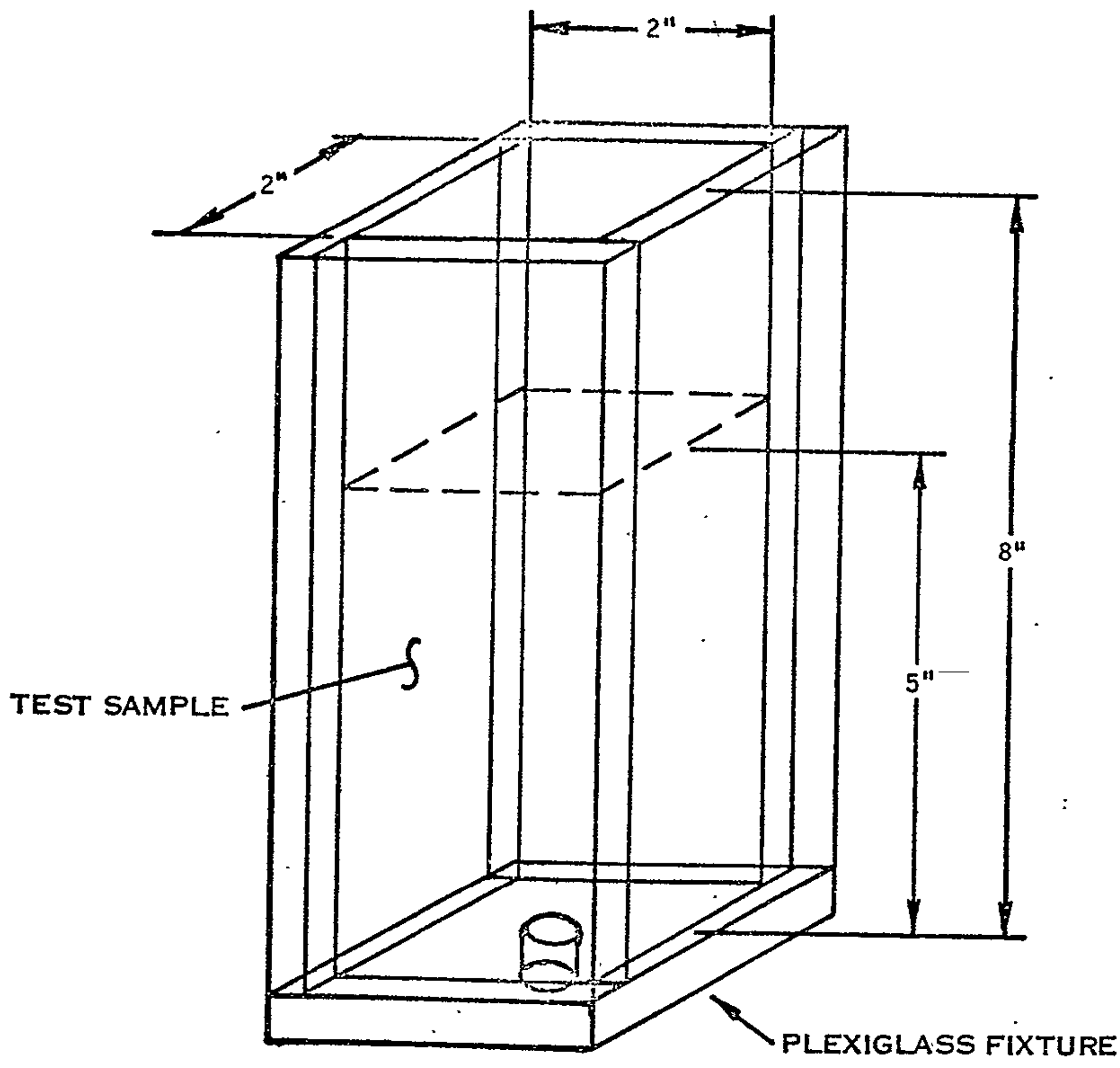
TABLE G4-2 (Continued

Material	Supplier
Super Sponge #6B Cellulose	American Sponge & Chamois Co. Inc. 47-00 34th Street Long Island City, New York
Mediterranean Ocean Sponge	American Sponge & Chamois Co. Inc. 47-00 34th Street Long Island City, New York

TABLE G4-3

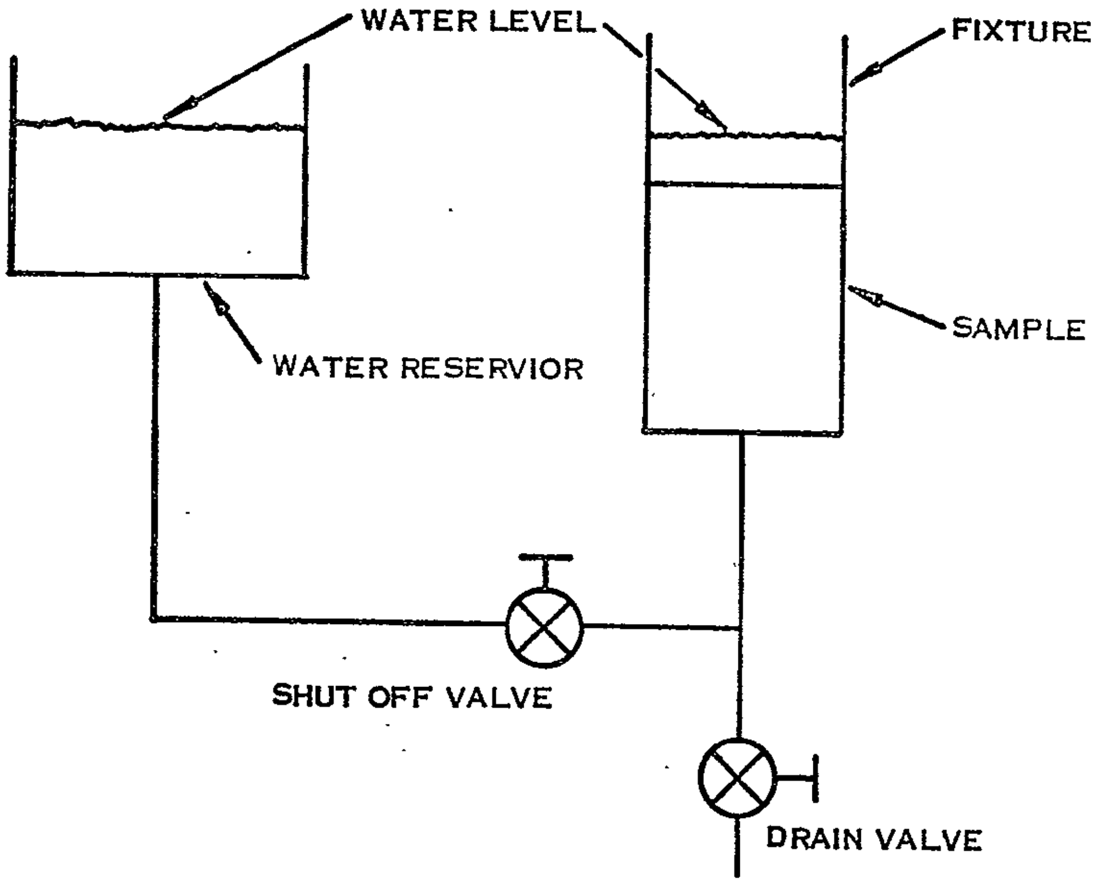
CANDIDATE SPONGE PROPERTIES

Material	Density Kg/m^3 (Lbs/Ft3)	Wicking Height m (Inches)	Water Capacity Kg H_2O/m^3 Sponge (Lbs H_2O/Ft^3 Sponge)	Volume Change % (H_2O Saturated)	Water Retention After 27.6 KPa (4 Psi) Compression Cycle Kg H_2O/m^3 Sponge (Lbs H_2O/Ft^3 Sponge)	Useable Water Capacity Kg H_2O/m^3 Sponge (Lbs H_2O/Ft^3 Sponge)	Volume Change From Original %	Weight Change From Original %	Wicking Height m (Inches)
Scott "Aquell" Polyurethane	34.8 (2.17)	4.4×10^{-2} (1.75)	490 (30.6)	+5.3	91.3 (5.7)	398.7 (24.9)	+21	0	3.2×10^{-2} (1.25)
Natural Sponge "Mediterranean"	20.0 (1.25)	1.3×10^{-2} (0.5)	287 (17.9)	+4.2	114 (7.1)	173 (10.8)	+9	0	0 (0)
Amsco "Super Cel" #85 Cellulose	58.0 (3.62)	4.4×10^{-2} (1.75)	388 (24.2)	+2.7	253 (15.8)	135 (8.4)	-2	-14	6.3×10^{-2} (2.5)
Amsco "Super Sponge" #6B Cellulose	68.4 (4.27)	5.7×10^{-2} (2.25)	407 (25.4)	+5.0	244 (15.2)	163 (10.2)	-29	-44	8.3×10^{-2} (3.25)



TEST FIGURE

FIGURE G-4-1



WATER CAPACITY SETUP

FIGURE G-4-2

APPENDIX H

EVALUATION OF ROTARY SEPARATOR PRIME MOVERS

H1.0 INTRODUCTION

In order to properly assess the various rotary separator concepts, it was necessary to establish the means of driving each device. Three prime movers were considered; independent motor (low speed); fan motor with gear box (low speed); fan motor direct drive (high speed).

H2.0 DISCUSSION

In considering use of the fan motor for driving the separator, several options were evaluated. These were, use of a low speed device coupled by gear box to the fan motor, and the use of a high speed device directly coupled to the fan motor.

Direct coupling of the fan motor to the separator gear box could conceivably reduce the fan reliability due to the addition of high speed bearings and the gear train, thus a method of decoupling the gear train was devised. This device requires the addition of an electromechanical friction clutch, a fan speed sensor, separator clutch speed sensor and electronic control system (see Figure H2-1). If fan speed drops below 80% of normal operating speed or if the separator clutch speed drops below 90% of actual fan speed, the electronic control system activates a solenoid to disengage the clutch. The control circuitry would be designed to permit normal start up without disengaging the clutch also (fan speed lower than 80% of normal operating speed in this mode). The weight and volume impact of this device is reflected in Table H2-1.

The use of a high speed separator was evaluated for devices sized to pass full gas flow and sized to pass the by-pass flow from the slurper or scupper. The prime evaluation factor was the power required to drive the separator which was determined using the relationship:

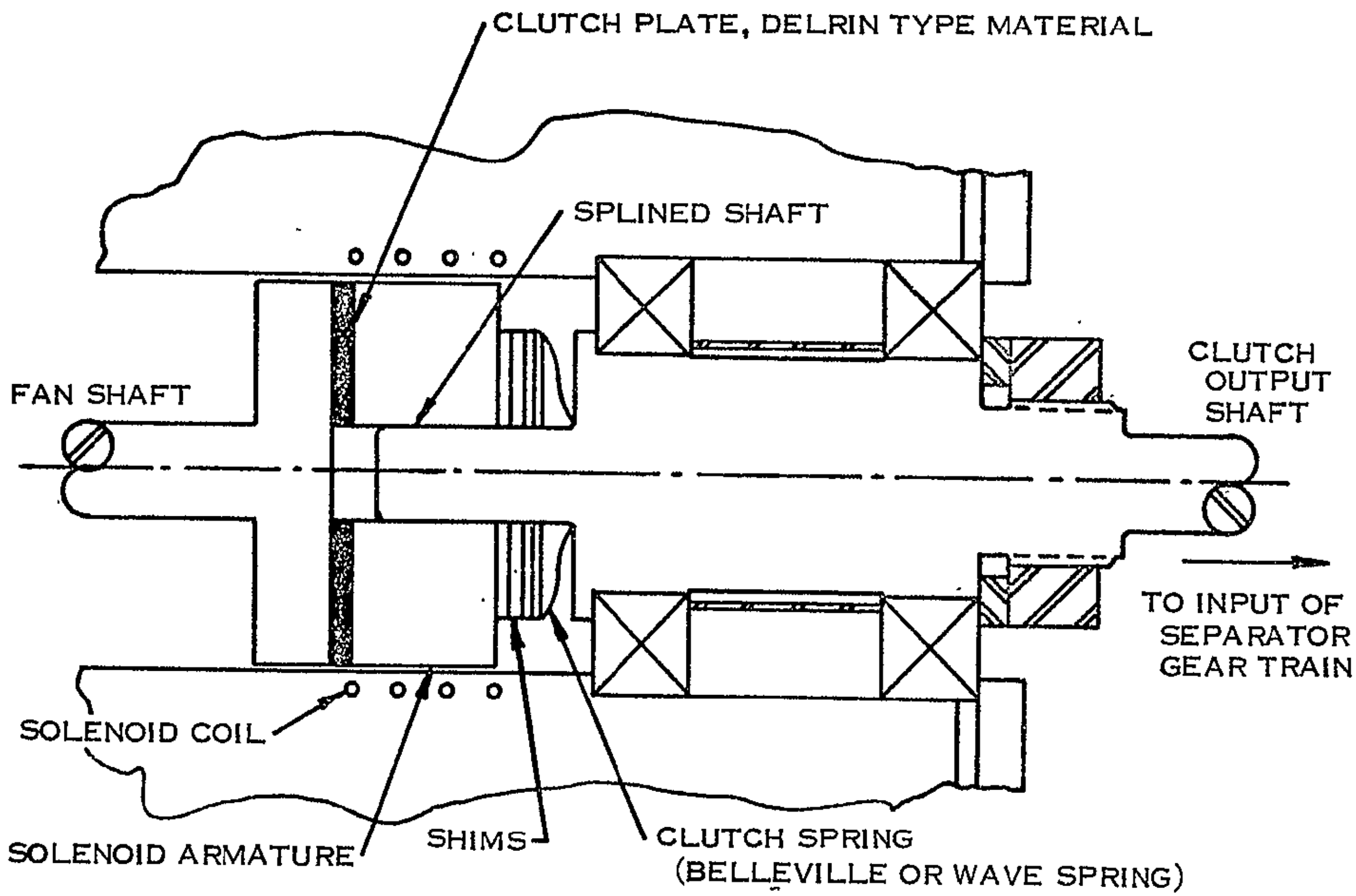
$$\text{Power} = \frac{\text{Torque X Speed}}{\text{motor efficiency}}$$

Figure H2-2 shows the power required vs. separator drum diameter at a constant speed of 1855 rad/sec (18,000 rpm).

The size of the drum required is related to the gas flow and allowable pressure drop. For a device to be located in the main flow stream a minimum diameter of 7.6 cm (3 in.) is required while for a device located in a slurper or scupper by-pass line a 2.54 cm (1 in.) diameter device is acceptable.

In order to confirm the feasibility of high speed separator operation, the feasibility separator, shows in Figure H2-3 was fabricated and tested. The tests confirmed that a separator can be designed to operate at 1855 RAD/Sec (18,000 rpm) and that it requires no more power than a low speed device.

The weight and volume for each concept are summarized in Table H2-1. The minimum weight and volume approach was selected as the optimum for each rotary separator concept.



CLUTCH
Figure H2-1

Hamilton Standard
DIVISION OF UNITED AIRCRAFT CORPORATION

		SINGLE STAGE ROTARY SEPARATOR	1ST STAGE SCUPPER 2ND STAGE FAN SEPARATOR	1ST STAGE SCUPPER 2ND STAGE ROTARY SEPARATOR	1ST STAGE SLURPER 2ND STAGE ROTARY SEPARATOR	SINGLE STAGE FAN/ SEPARATOR
INDEPENDANT MOTOR (LOW SPEED)	HARDWARE	0.54 KG (1.2#) * 491 CC (30 IN^3)	0.5 KG (1.1#) 491 CC (30 IN^3)	0.36 KG (0.8#) 246 CC (15 IN^2)	0.36 KG (0.8#) 246 CC (15 IN^3)	NA
	POWER PENALTY	0.45 KG (1#) 328 CC (20 IN^3)	0.36 KG (0.8#) 262 CC (16 IN^2)	0.18 KG (0.4#) 131 CC (8 IN^2)	0.18 KG (0.4#) 131 CC (8 IN^3)	NA
USE FAN MOTOR WITH GEAR BOX (LOW SPEED)	HARDWARE	0.86 KG (1.9#) 574 CC (35 IN^3)	0.82 KG (1.8#) 574 CC (35 IN^3)	0.66 KG (1.5#) 330 CC (20 IN^3)	0.66 KG (1.5#) 330 CC (20 IN^3)	NA
	POWER PENALTY	0.45 KG (1#) 131 CC (8 IN^3)	0.36 KG (0.8#) 262 CC (16 IN^3)	0.18 KG (0.4#) 131 CC (8 IN^2)	0.18 KG (0.4#) 131 CC (8 IN^3)	NA
USE FAN MOTOR DIRECT DRIVE (HIGH SPEED)	HARDWARE	0.23 KG (0.5#) 246 CC (15 IN^3)	0.18 KG (0.4 #) * 246 CC (15 IN^3)	0.09 KG (0.2#) * 82 CC (5 IN^3)	0.09 KG (0 2#) * 82 CC (5 IN^3)	0.66 KG (1.5#) 869 CC (53 IN^3)
	POWER PENALTY	4.4 KG (9.6#) 3147 CC (192 IN^3)	0.36 KG (0.8#) 262 CC (16 IN^3)	0.18 KG (0.4#) 131 CC (8 IN^3)	0.18 KG (0.4#) 131 CC (8 IN^3)	4.4 KG (9.6#) 3147 CC (192 IN^3)

*DENOTES SELECTED CONCEPT

3,147 cc (192 in^3)

3,147 cc (192 in^3)

TABLE H2-1 HARDWARE AND POWER PENALTY WEIGHT AND VOLUME VS SEPARATOR PRIME MOVER

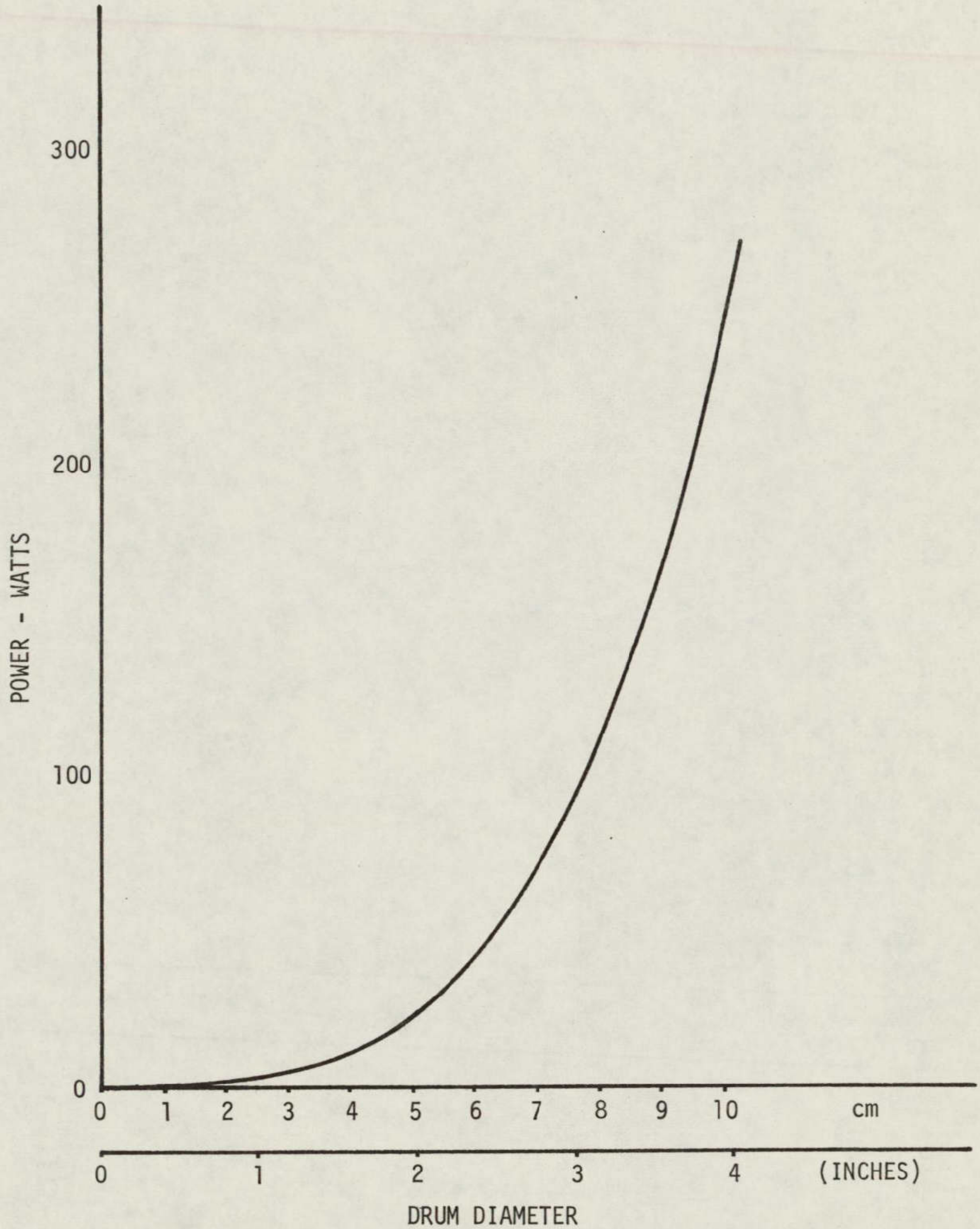


FIGURE H2-2

POWER VS DRUM DIAMETER

1855 RAD/SEC (18,000 RPM)

H2.0 Continued

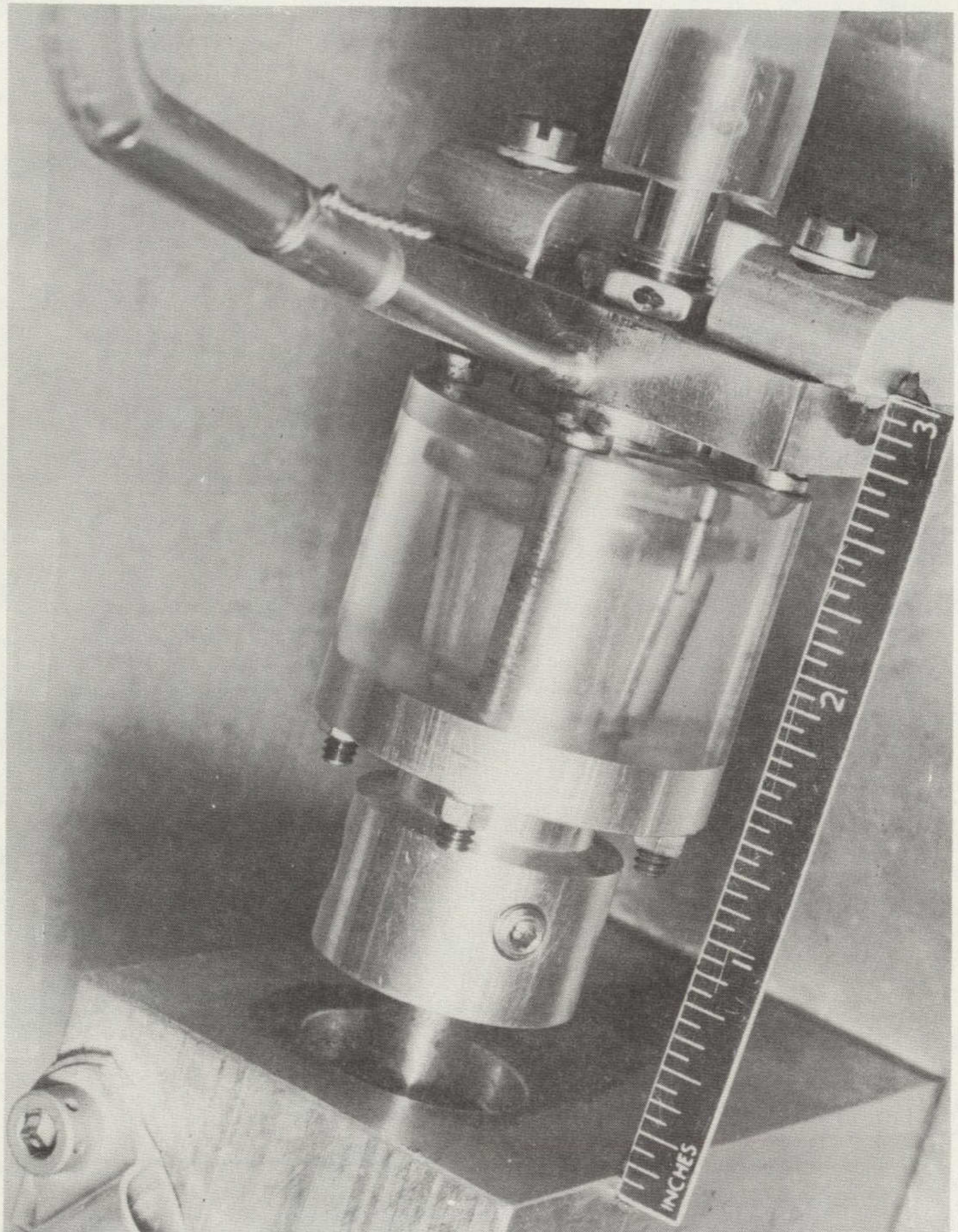


FIGURE H2-3
ROTARY SEPARATOR

SS-11410-4

APPENDIX I

LCG THERMAL CONTROL STUDY

I1.0 INTRODUCTION

The evaluation of the candidate LCG thermal control methods to the absolute criteria resulted in identification of LCG inlet flow control and LCG inlet temperature control as competitive concepts. The following study was conducted to determine which of these two methods was more suited for use in the TCS.

I2.0 DISCUSSION

Figure I2-1 shows the LCG portion of an EVA system utilizing LCG inlet flow control. It includes a pump, vehicle umbilical connector, HRS, thermal control valve (TCV) and LCG. LCG thermal comfort is achieved by modulating the TCV which varies the amount of water which bypasses the LCG.

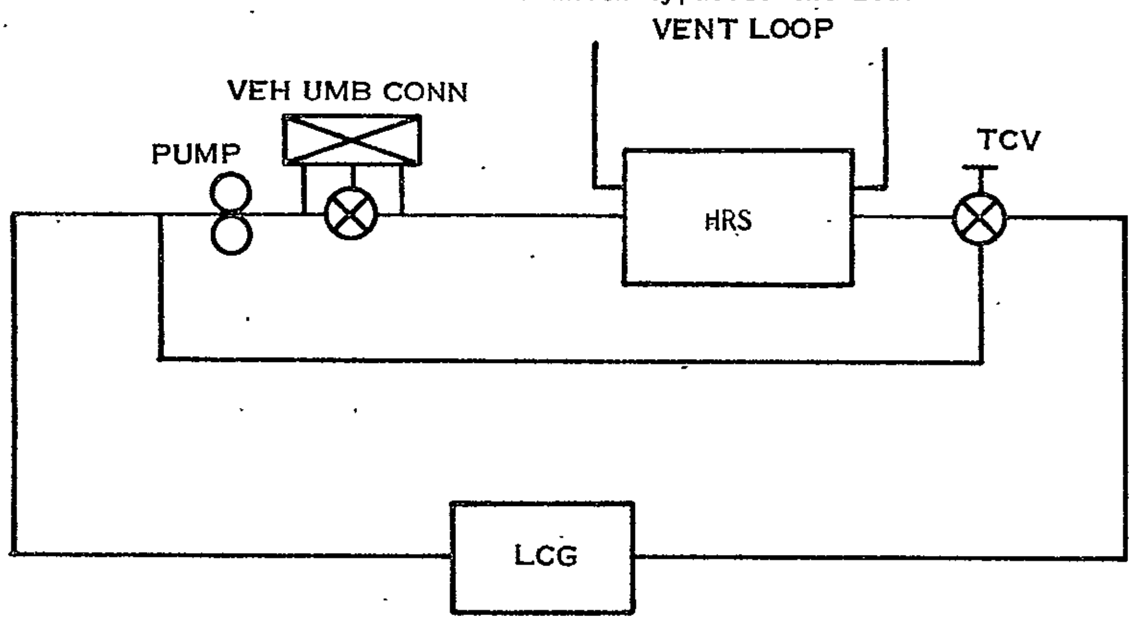


FIGURE I2-1
LCG INLET FLOW CONTROL CONCEPT

The basic system can be modified to utilize LCG inlet temperature control by relocating the HRS bypass line from the upstream side of the pump to the downstream side of the pump as shown in Figure I2-2.

I2.0 Continued

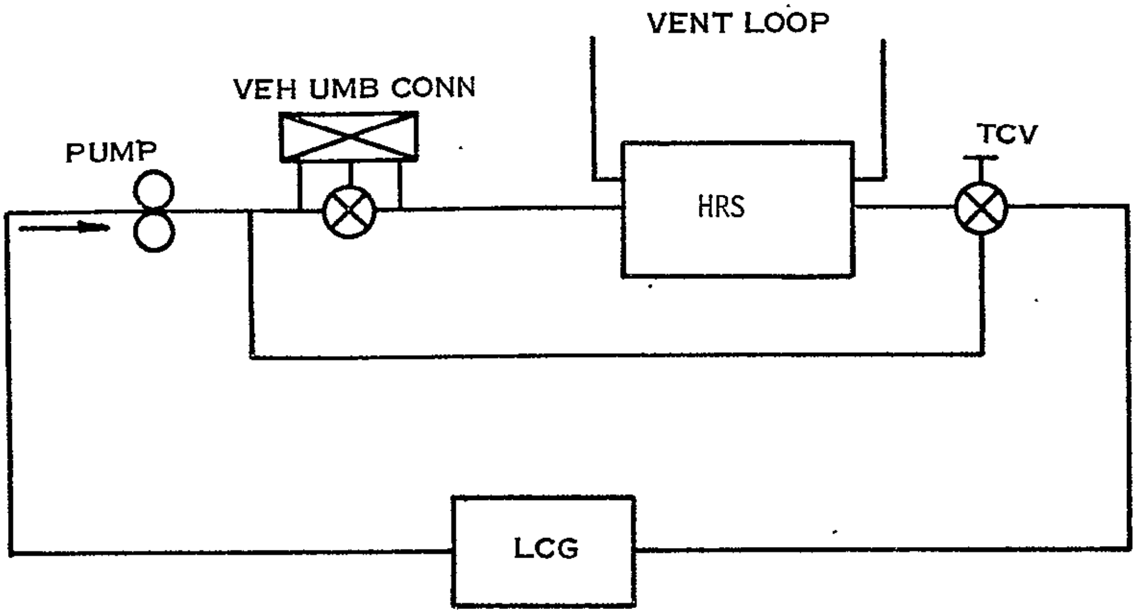


FIGURE I2-2
LCG INLET TEMPERATURE CONTROL CONCEPT

During normal EVA operation, LCG thermal comfort is achieved by bypassing the flow around the HRS as was done in the Apollo PLSS. During umbilical operation, manual variation of the TCV setting varies the flow through the umbilical. At low heat loads, the flow through the umbilical is reduced and under these conditions, the heat leak between the umbilical outlet and inlet hoses and the heat leak into the umbilical can result in sublimator inlet water temperature in excess of 70°F. Since this water is the heat sink for the vent loop, the vent loop dew point can be greater than 70°F. There is no weight or volume penalty associated with this concept.

A second approach for achieving LCG thermal control via LCG inlet temperature control is shown in Figure I2-3.

I2.0 Continued

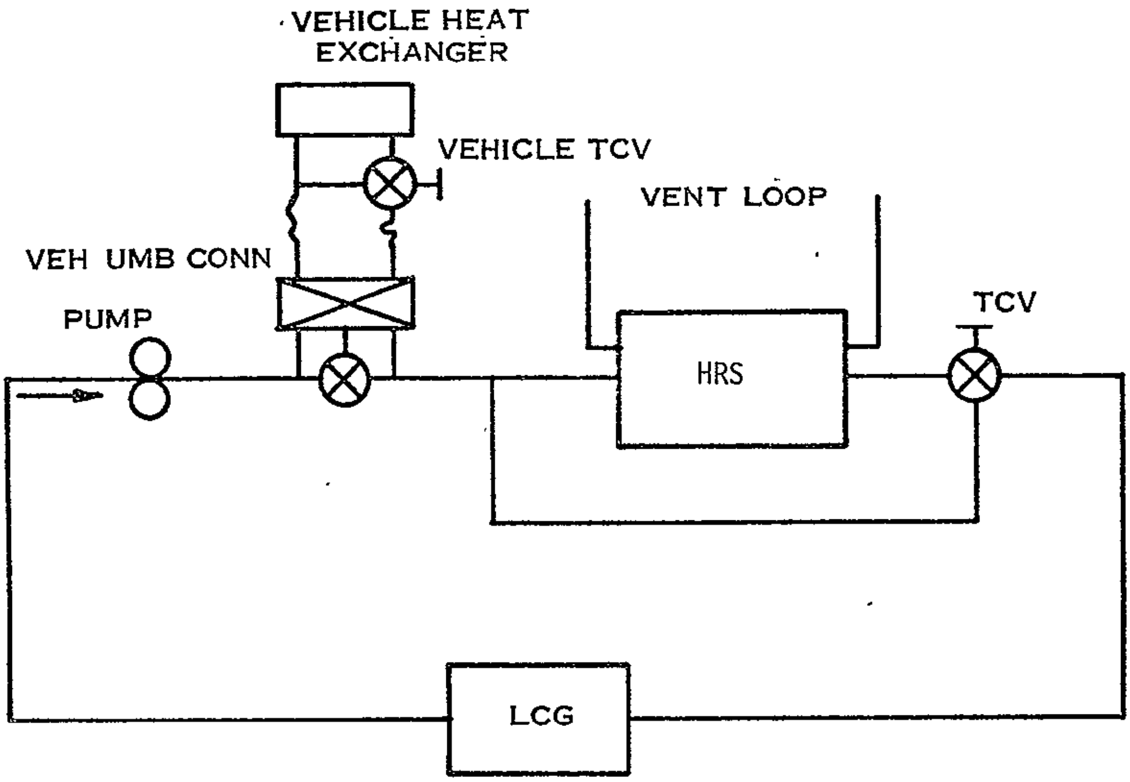


FIGURE I2-3

During normal EVA operation, LCG thermal comfort is achieved by bypassing the flow around the HRS as was done with the previous system. During umbilical operation, the EVLSS TCV is left in the maximum heat load position, and crewman LCG thermal control is achieved by varying the TCV located in the vehicle. This requires remote control by the crewman to operate the vehicle TCV or requires a second crewman to adjust the vehicle TCV.

Under low heat load conditions, the water leaving the pump is approximately 80°F and, since only limited cooling is required, most of the flow is bypassed around the vehicle heat exchanger. Since the water returning to the EVLSS heat sink for the vent loop is approximately 78°F, the vent loop dew point will exceed 78°F. Addition of the vehicle TCV would increase the vehicle weight by approximately .28 kg (~.6 lb). There would be no increase in EVLSS volume.

Another concept which utilizes the LCG inlet temperature control requires the addition of a heat exchanger to the EVLSS and a pump to the vehicle as shown in Figure I2-4. During umbilical operation, coolant from the vehicle maintains the EVLSS heat exchanger at essentially a constant temperature and LCG

I2.0 Continued

inlet temperature control is achieved by varying the flow around the heat exchanger with the TCV.

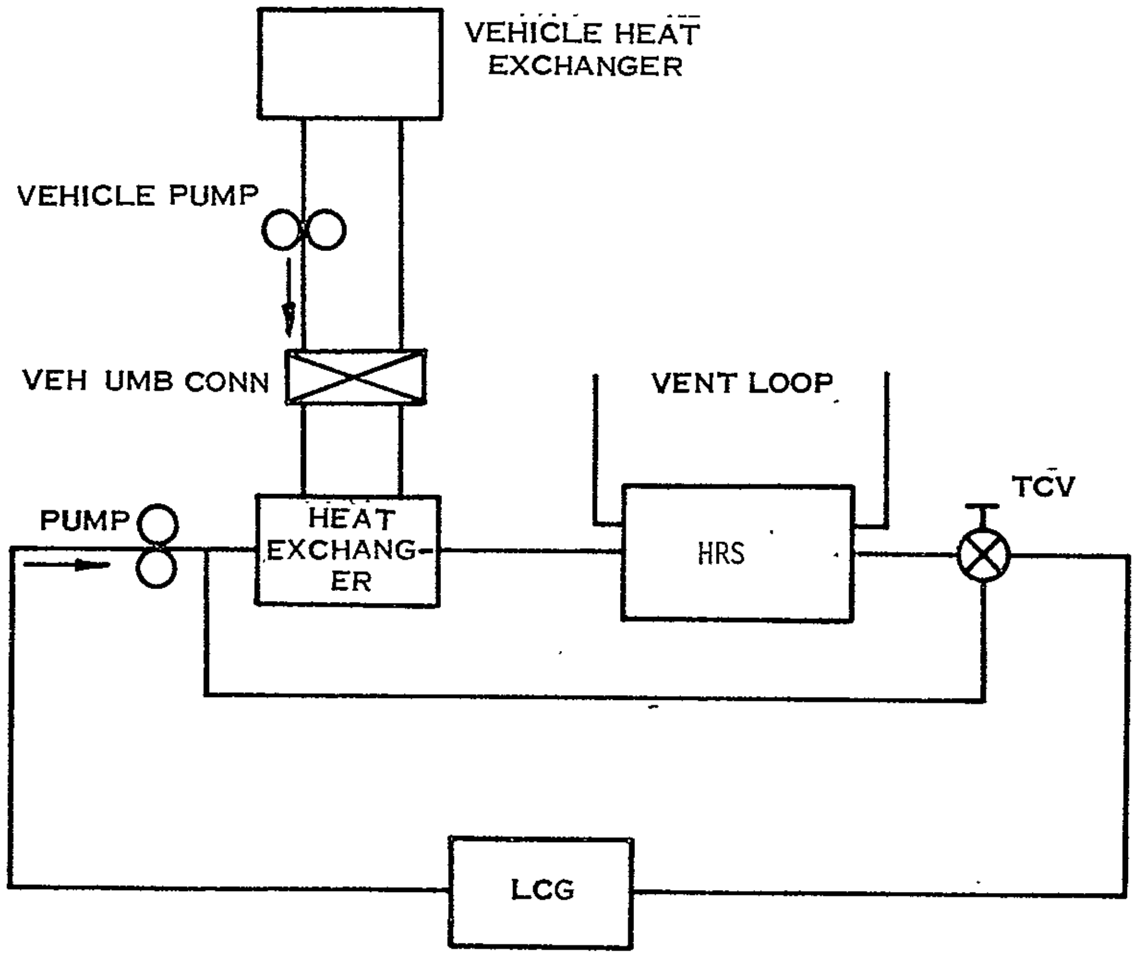


FIGURE I2-4

The following summarizes the weight and volume penalties and the dew point performance predicted for this concept.

I2.0 Continued

Weight

EVLSS Heat Exchanger	1.68 kg (~ 3.7 lb)
Pump Weight	1.14 kg (~ 2.5 lb)
Power Penalty per EVA	.07 kg (~ .15 lb)
Total Vehicle Launch Weight Penalty	
EVLSS Heat Exchangers	3.36 kg (~ 7.4 lb)
Vehicle Pump	1.14 kg (~ 2.5 lb)
Power Penalty for Four Dual EVA's	.28 kg (~ .6 lb)
	4.78 kg (10.5 lb)

Volume

EVLSS Package Volume Increase	1900 cm^3 (~116 in^3)

Performance

Dew Point when Operating on HRS	44 - 48°F
Dew Point when Operating on Umbilical	53 - 58°F

Figure I2-5 shows another concept utilizing LCG inlet temperature control. During umbilical operation, cooled water is returned to the EVLSS upstream of the sublimator but downstream of the EVLSS pump and TCV bypass line. A check valve is required to prevent umbilical water from entering the HRS bypass line. The water from the LCG mixes with the water from the vehicle in the sublimator, and the cooled mixture is returned to both the vehicle and the LCG. The temperature of the water returning to the LCG is controlled by varying the amount of water bypassed around the sublimator by adjusting the TCV.

I2.0 Continued

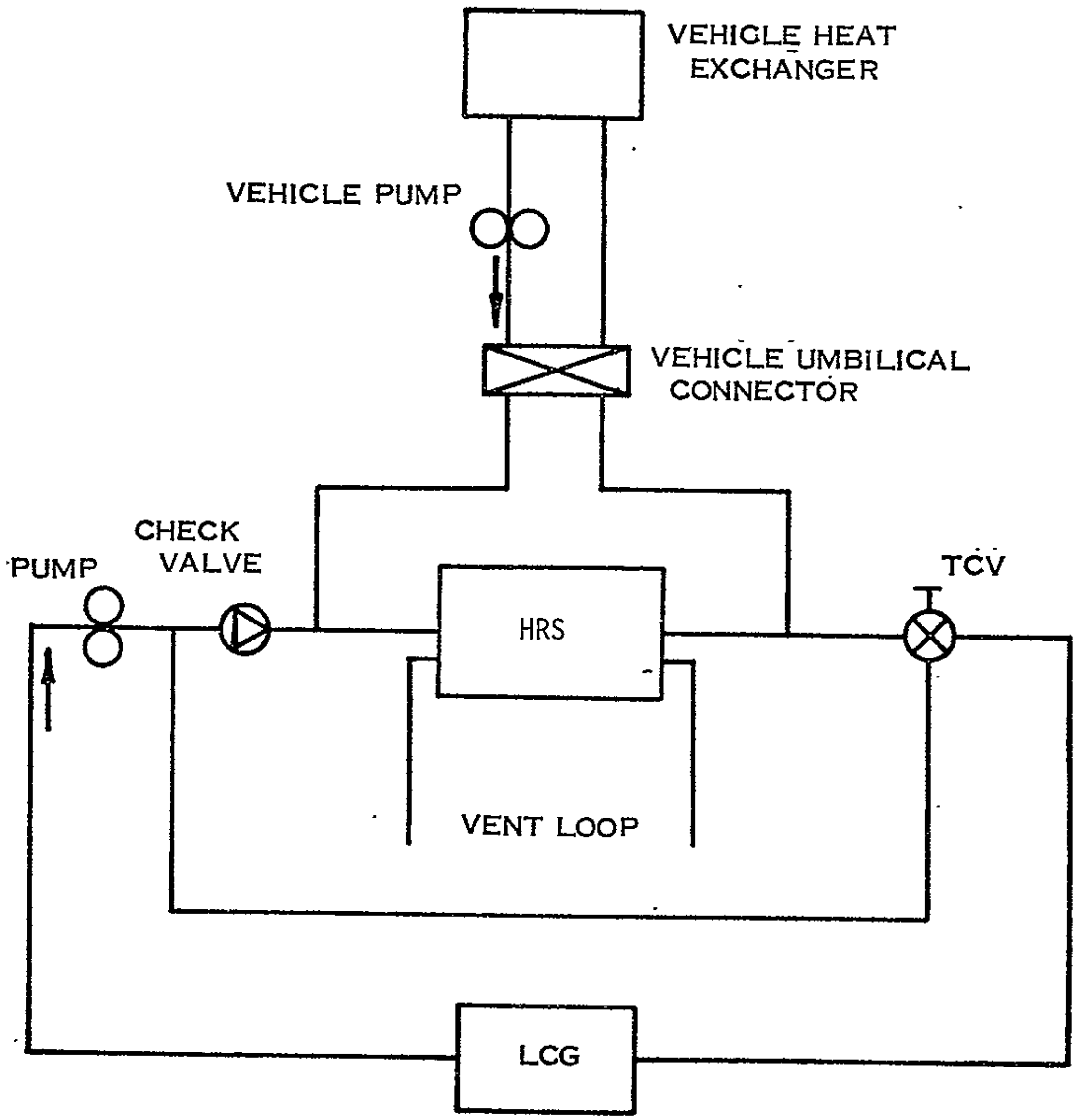


FIGURE I2-5

I2.0 Continued

The following summarizes the weight and volume penalties and dew point performance predicted for this concept:

Weight

Pump Weight	1.14 kg (~2.5 lb)
Check Valve	.05 kg (~ .1 lb)
Power Penalty per EVA	.07 kg (~ .15 lb)
Total Vehicle Launch Weight Penalty	
Two EVLSS Check Valves	.1 kg (~ .2 lb)
Vehicle Pump	1.14 kg (~2.5 lb)
Power Penalty for Four EVA's	.28 kg (~ .6 lb)
	1.52 kg (~3.3 lb)

Volume

Negligible Impact on EVLSS Volume

Performance

Dew Point when Operating on HRS	44 - 48°F
Dew Point when Operating on Umbilical	63 - 68°F

Figure I2-6 depicts a fifth concept which utilizes LCG inlet temperature control. This concept requires the addition of a selector valve and HRS bypass line to the EVLSS and a pump to the vehicle. During normal EVA operation on the sublimator, the selector valve is set to allow full flow through the sublimator. During umbilical operation, the selector valve is set to bypass all of the LCG water around the HRS. The cooled umbilical water is returned to the EVLSS upstream of the HRS. The umbilical water passes through the HRS, cooling the vent loop and then mixes with the LCG water downstream of the sublimator bypass line. The temperature of the water returning to the LCG is controlled by adjusting the TCV to set the amount of LCG water which mixes with the umbilical water.

I2.0 Continued

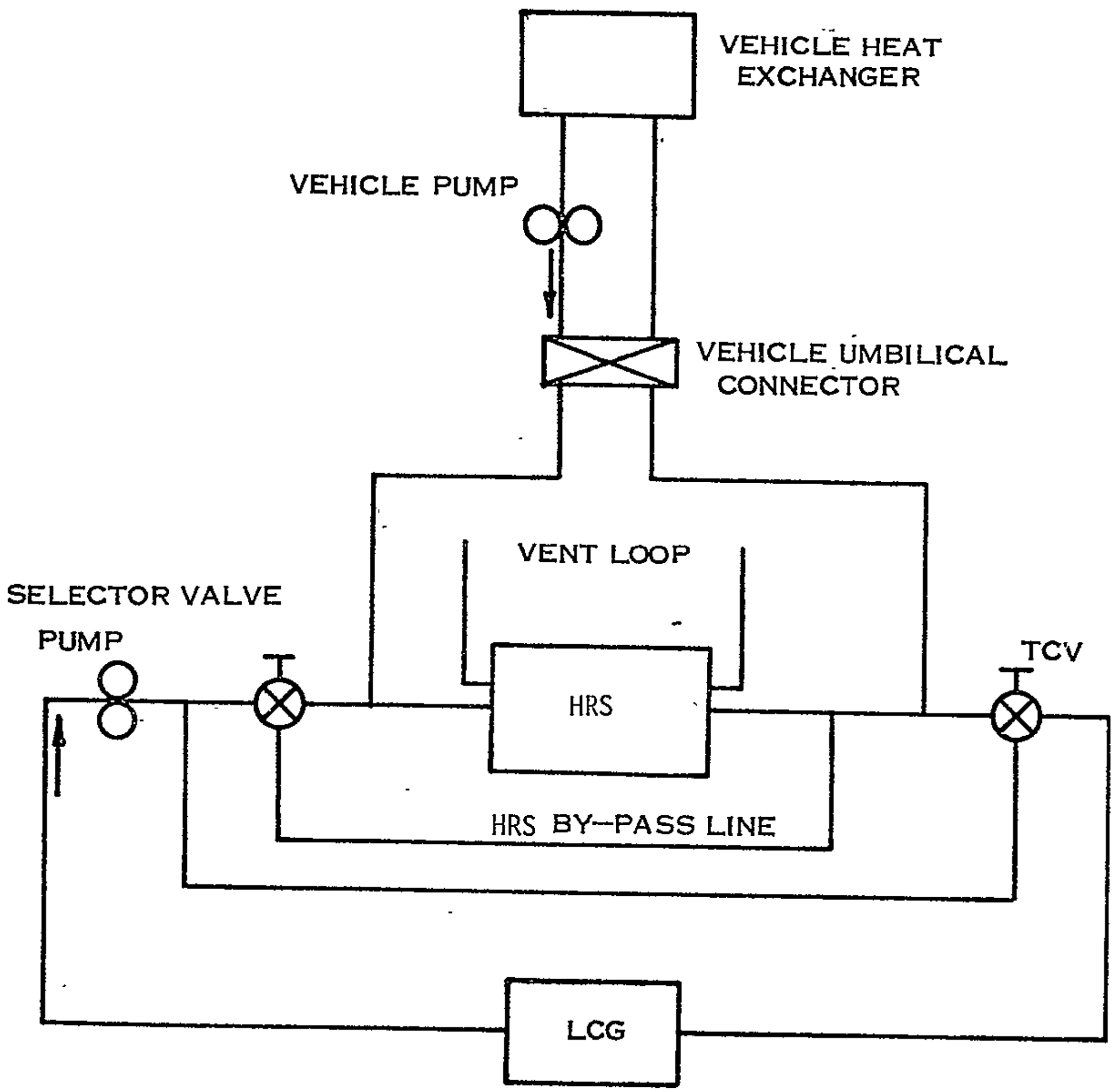


FIGURE I2-6

I2.0 Continued

The following summarizes the weight and volume penalties and the dew point performance predicted for this concept:

Weight

Pump Weight	1.14 kg (~2.5 lb)
Selector Valve	.14 kg (~ .3 lb)
Bypass Line	Negligible
Power Penalty per EVA	.07 (~ .15 lb)
Total Vehicle Launch Weight Penalty	
Two EVLSS Selector Valves	.28 kg (~ .6 lb)
Vehicle Pump	1.14 kg (~2.5 lb)
Power Penalty for Four EVA's	.28 kg (~ .6 lb)
	1.7 kg

Volume

Negligible Impact on EVLSS Volume

Performance

Dew Point when Operating on HRS	44 - 48°F
Dew Point when Operating on Umbilical	50 - 55°F

Summary

The following table summarizes the weight and volume penalties and lists the expected vent loop dew points for each of the LCG inlet temperature control concepts considered. Concepts 1, 2 and 4 are unacceptable since visor fogging can occur because of the high dew point temperatures. Of the remaining two approaches, concept 5 has the least weight and volume impact and would be the selected approach if LCG inlet temperature control was to be used for LCG thermal control of the EVLSS. However, use of LCG inlet temperature control offers no advantage over the LCG inlet flow control while having a 1.7 Kg (3.7 lb) penalty. Thus, the LCG flow control is the selected concept.

Concept Number	1	2	3	4	5
Figure Number	2	3	4	5	6
EVLSS Weight Increase	0	0	1.68 kg (~3.7 lb)	.05 kg (~.1 lb)	.14 kg (~.3 lb)
Vehicle Weight Increase	0	.28 kg (~.6 lb)	1.42 kg (~3.1 lb)	1.42 kg (~3.1 lb)	1.42 kg (~3.1 lb)
Total Launch Weight Increase	0	.28 kg (~.6 lb)	4.78 kg (~10.5 lb)	1.52 kg (~3.3 lb)	1.7 kg (~3.7 lb)
EVLSS Volume Increase	0	0	1900 cm^3 (~116 in^3)	Negligible	Negligible
Vent Loop Dew Point	>70°F	>80°F	53 - 58°F	63 - 68°F	50 - 55°F

APPENDIX J

TCS CONCEPT DESCRIPTIONS

CONCEPT #1

This concept consists of a bubble expansion tank WMS, a three (3) fluid sublimator HRS, a single stage motor/rotary separator for condensate control and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

During operation, water enters from the LCG and is circulated, by the EVLSS pump, through the vehicle umbilical connector shutoff valve, the sublimator, the temperature control valve (TCV) and back to the LCG. The LCG water in the sublimator is the heat sink for the vent loop and is in turn cooled via heat transfer to the porous plate of the sublimator. During umbilical operation, the umbilical connector shutoff valve is closed routing all water to a heat exchanger in the vehicle which replaces the porous plate heat sink. Thermal comfort control is achieved by the TCV which varies the water flow to the LCG. LCG pressurization and makeup water is supplied via the check valve between the feed water circuit and the LCG.

The vent loop flow coming from the suit enters the sublimator where it is cooled below the dew point condensing water. The gas plus the condensed water enters the motor/rotary separator which separates the condensed water from the gas stream, and the gas is then returned to the suit via the fan. When passing through the fan, the gas is super heated above the dew point to prevent visor fogging. The separated water is delivered to the feed water circuit through a relief valve which prevents the introduction of gas to the feed water circuit.

The expansion tank is sized to accommodate the gas released from the saturated water when the pressure in the main reservoir drops from 248 to 27.6 KN/M^2 (36 to 4 psia), and the water generated during one half hour of pre EVA umbilical operation; or, the tank will accommodate the water separated during a four and one half hour EVA in the non-venting mode.

Recharge of the system involves the following steps.

Open the shutoff valve between the two tanks.
Connect the drain fitting.
Open the EVLSS O_2 supply valve and hold.
Close the valve between the two tanks.
Close the O_2 supply valve.
Open the dump valve.
Connect the fill fitting and hold.
Disconnect the fill fitting.
Close the dump valve.

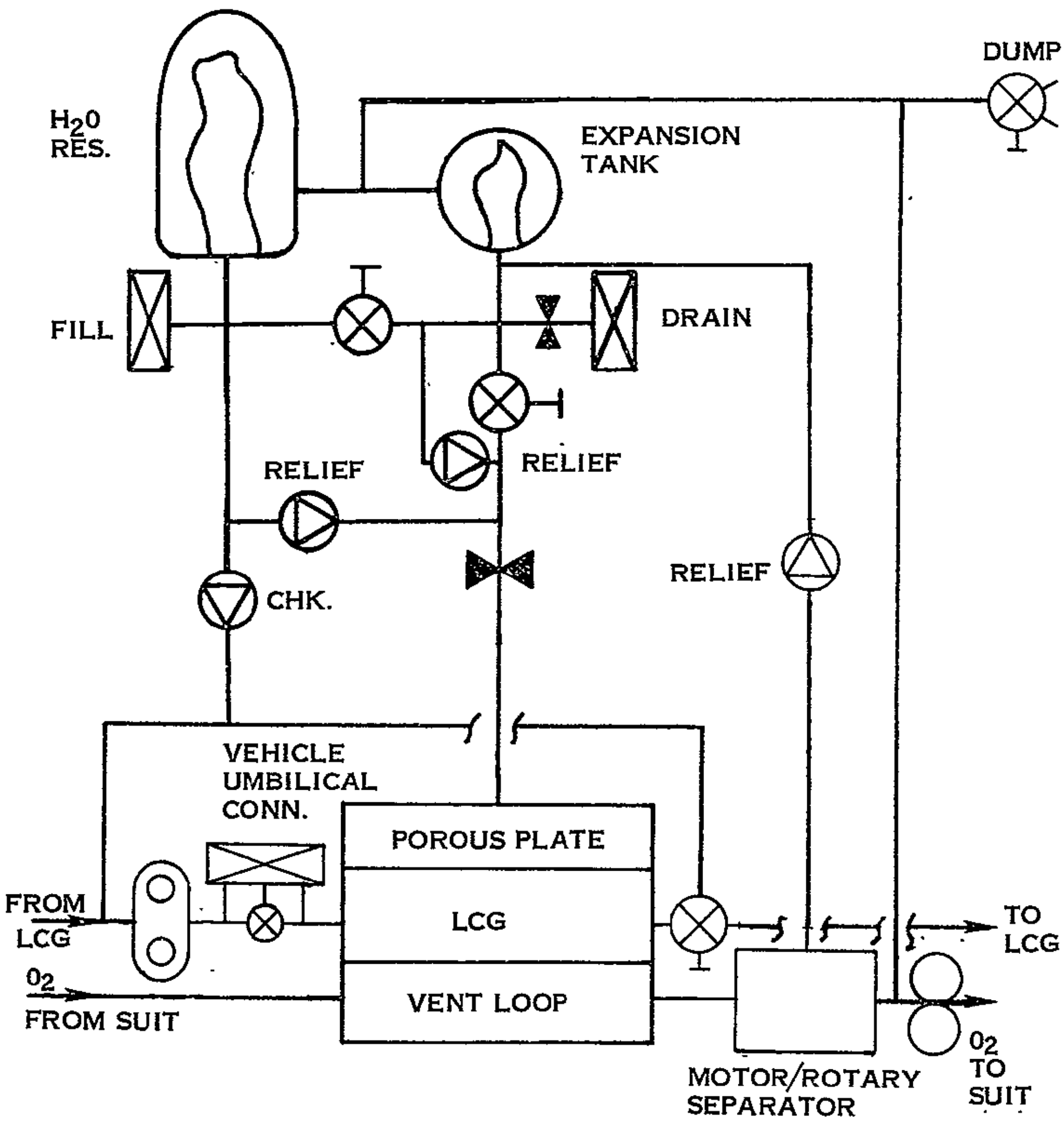
For normal EVA, the valve between the tanks is opened before donning the EVLSS and the valve upstream of the porous plate is opened to activate the HRS. For non-venting EVA, both valves are left closed.

If the motor/rotary separator relief valve were to fail open with the feed water lines dry and the shutoff valve open, the vent loop would exhaust to vacuum. The flow limiting orifice in the line to the sublimator was included to control gas leakage under these conditions.

A component weight and volume breakdown and the vehicle weight penalty for this concept are as follows:

Component	System Weight Kg	(lbs)	System Volume (in^3)	m^3
Primary H_2O Res.	1.0	(2.2)	(394)	.00642
Expansion Tank	.36	(.8)	(75)	.00123
H_2O	3.22	(7.1)		--
Dump Valve	.09	(.2)	(6)	.000098
Fill Fitting	.045	(.1)	(3)	.000040
Two Shutoff Valves	.18	(.4)	(12)	.000196
Three Relief Valves	.136	(.3)	(3)	.000049
Check Valve	.045	(.1)	(1)	.000016
Pump	.59	(1.3)	(15)	.000245
Vent Conn.	.23	(.5)	(6)	.000098
Rotary Separator	.54	(1.2)	(30)	.00049
Sublimator	1.59	(3.5)	(184)	.0030
TCV	.14	(.3)	(6)	.000098
Drain Fitting	.045	(.1)	(3)	.000049
Package	1.36	(3.0)	(80)	.0013
Power Penalty			(40)	.00065
Pump	.36	(.8)		
Gas Delta P	.36	(.8)		
Rotary Separator	.18	(.4)		
Total	10.5	(23.1)	(858)	.0140

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (33.9 pounds) 15.4 Kg



CONCEPT 1 - SUBLIMATOR, BUBBLE EXPANSION TANK,
SINGLE STAGE /ROTARY SEPARATOR

CONCEPT #2

This concept consists of a bubble expansion tank WMS, a three (3) fluid sublimator HRS, a single stage elbow wick separator for condensate control and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

This concept is similar to concept #1 except that the motor/rotary separator is replaced by an elbow wick separator which is sized to contain the water separated during a four and one half hour EVA. Since the separated water is stored rather than utilized as feed water, the H_2O reservoir and expansion tank are larger than the tanks in concept 1.

Recharge of the system involves the following steps.

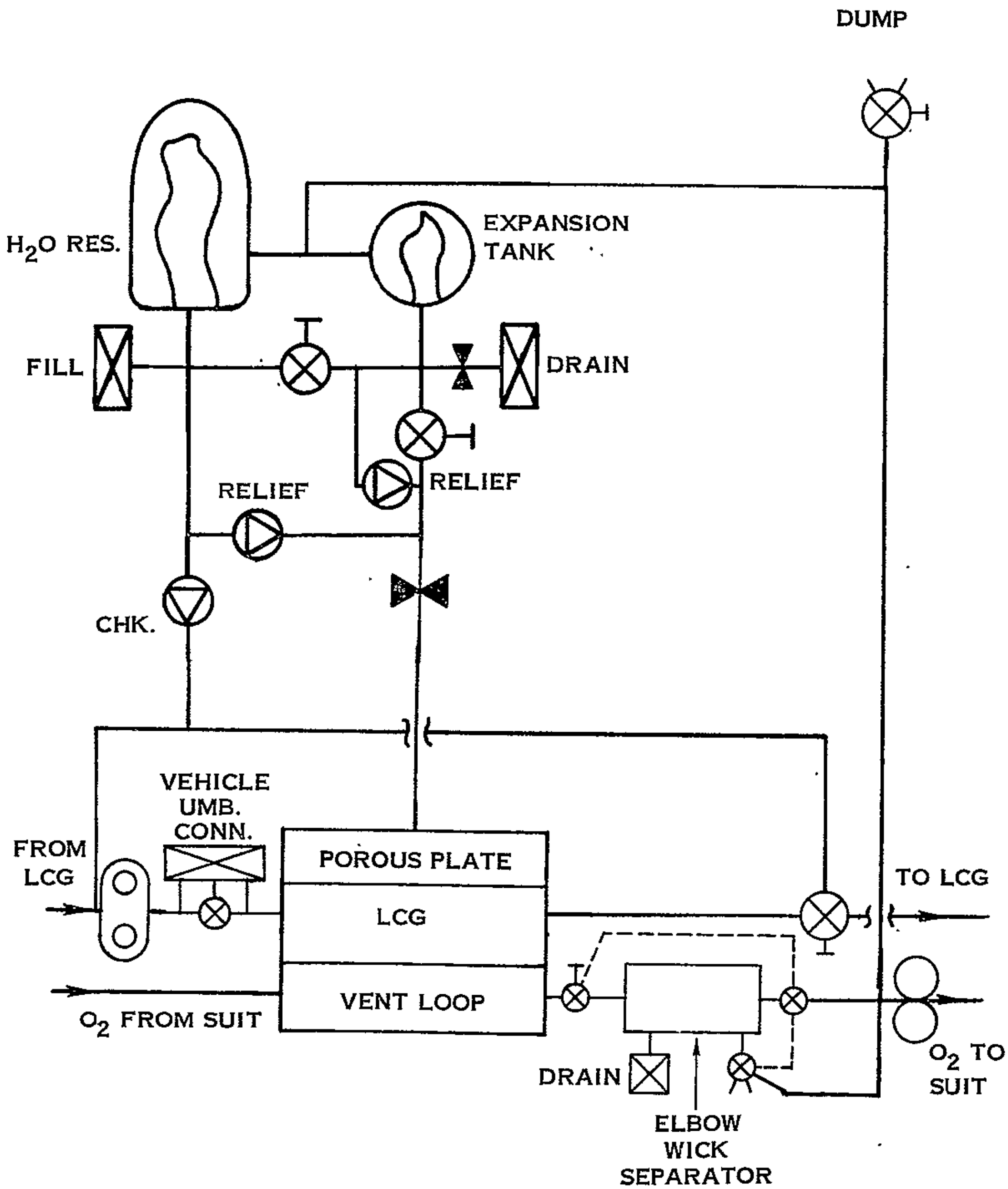
Open the shutoff valve between the two tanks.
Connect drain lines to the drain connector.
Close the three tier valve.
Open the EVLSS O_2 supply valve and hold.
Close the valve between the tanks.
Close the EVLSS O_2 supply valve.
Open the three tier valve.
Open the dump valve.
Connect the fill fitting and hold.
Disconnect the drain lines from the drain fittings.
Close the dump valve.

The backside of the bladder in the separator must be vented to vacuum during EVA; hence, failure of the bladder or the three tier valve could expose the vent loop to vacuum.

A component weight and volume breakdown and the vehicle weight penalty for this concept are as follows:

Component	System Weight Kg	(lbs)	System Volume (in^3)	m^3
Primary H_2O Reservoir	1.09	(2.4)	(446)	.0073
Expansion Tank	.36	(.8)	(85)	.0014
H_2O	3.68	(8.1)	--	
Dump Valve	.09	(.20)	(6)	.000098
Fill Fitting	.045	(.1)	(3)	.000049
Two Shutoffs	.18	(.4)	(12)	.0002
Two Reliefs	.09	(.2)	(2)	.000033
Check Valve	.045	(.1)	(1)	.000016
Pump	.59	(1.3)	(15)	.00025
Vehicle Connector	.23	(.5)	(6)	.000098
Elbow Wick Separator	1.14	(2.5)	(160)	.0026
3-In-1 Shutoff	.18	(.4)	(8)	.00013
Two Drain Fittings	.09	(.2)	(6)	.000098
Sublimator	1.59	(3.5)	(184)	.0030
TCV	.14	(.3)	(6)	.000098
Package	1.5	(3.3)	(91)	.0015
Power Penalty			(37)	.00061
Pump	.36	(.8)		
Gas Delta P	.5	(1.1)		
Total	11.9	(26.2)	(1,068)	.017

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (38 Pounds) 17.3 Kg



CONCEPT 2 -SUBLIMATOR, BUBBLE EXPANSION TANK, SINGLE STAGE ELBOW WICK SEPARATOR

CONCEPT #3

This concept consists of a bubble expansion tank WMS, a three (3) fluid sublimator HRS, a first stage elbow scupper/second stage fan separator condensate control system and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the TCS shutdown.

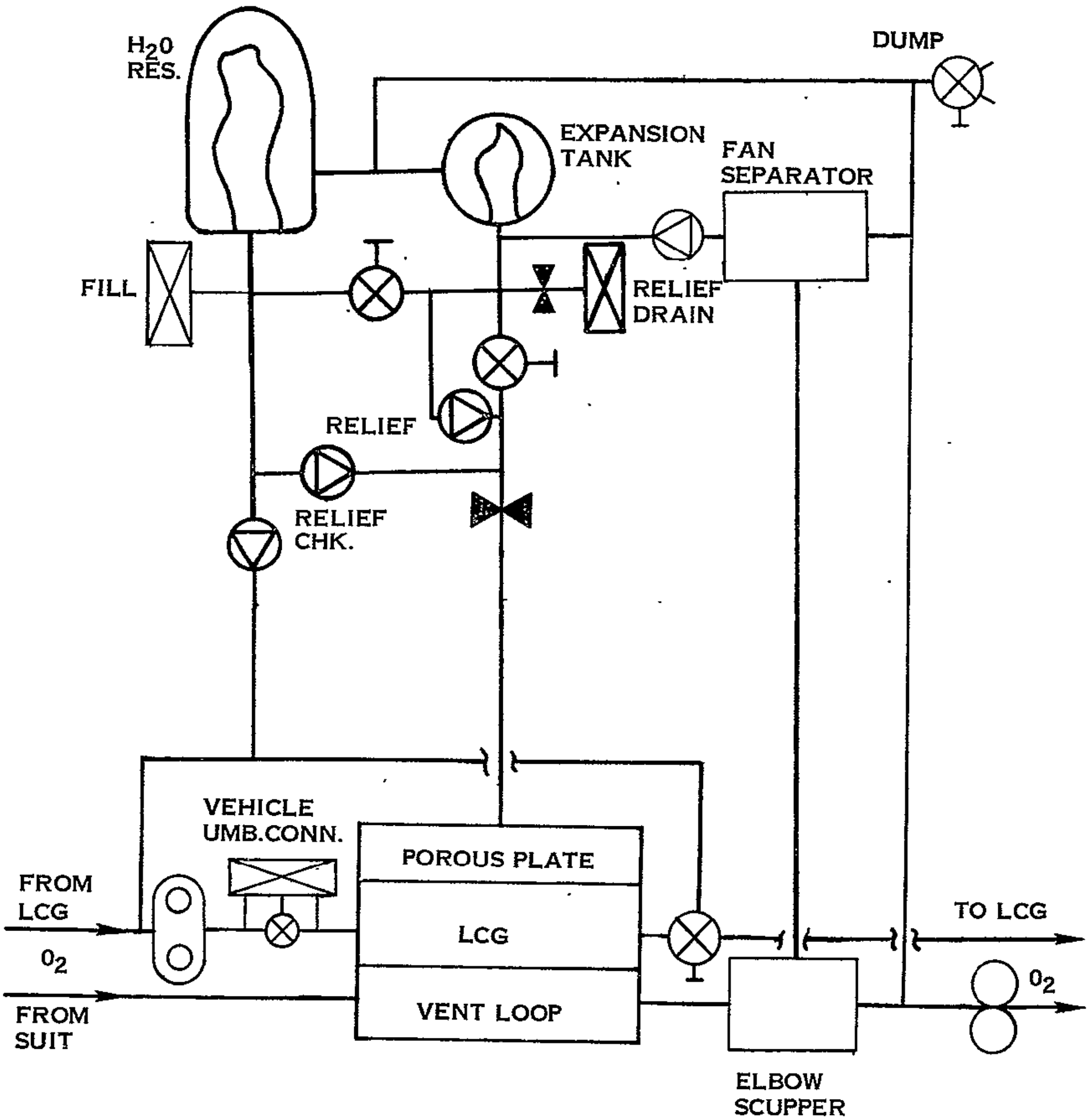
Operationally, this concept is similar to Concept #1. However, the humidity control is accomplished in two stages. The elbow scupper removes all of the condensate from the main gas stream and a small amount of gas. The fan separator pumps the condensate to the water management system and provides the necessary head to force flow through the secondary loop.

Recharge is accomplished by utilization of the steps outlined for Concept #1.

A component weight and volume breakdown and the vehicle weight penalty for this concept are as follows:

Component	System Weight Kg (lbs)	System Volume (in^3) m^3
Primary Reservoir	1.0 (2.2)	(394) .00642
Expansion Tank	.36 (.8)	(75) .00123
H_2O	3.22 (7.1)	--
Dump Valve	.09 (.2)	(6) .000098
Fill Fitting	.045 (.1)	(3) .000049
Two Shutoffs	.18 (.4)	(12) .0002
Three Reliefs	.14 (.3)	(3) .000049
Check Valve	.045 (.1)	(1) .000016
Pump	.59 (1.3)	(15) .00024
Vehicle Connector	.23 (.5)	(6) .000098
Fan Separator	.5 (1.10)	(30) .00049
Elbow Scupper	.14 (.3)	(8) .00013
Sublimator	1.59 (3.5)	(184) .003
TCV	.14 (.3)	(6) .000098
Drain Fitting	.045 (.1)	(3) .000049
Package	1.36 (3.0)	(80) .0013
Power Penalty		(40) .00065
Pump	.36 (.8)	
Fan Separator	.36 (.8)	
Gas Delta P	.36 (.8)	
Total	10.8 (23.7)	(866) .014

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (35.5 pounds) 16.1 Kg



CONCEPT 3 - SUBLIMATOR, BUBBLE EXPANSION TANK, 1ST STAGE SCUPPER 2ND STAGE FAN SEPARATOR

CONCEPT #4

This concept consists of a bubble expansion tank WMS, a three (3) fluid sublimator HRS, a first stage elbow scupper/second stage motor/rotary separator condensate control system and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

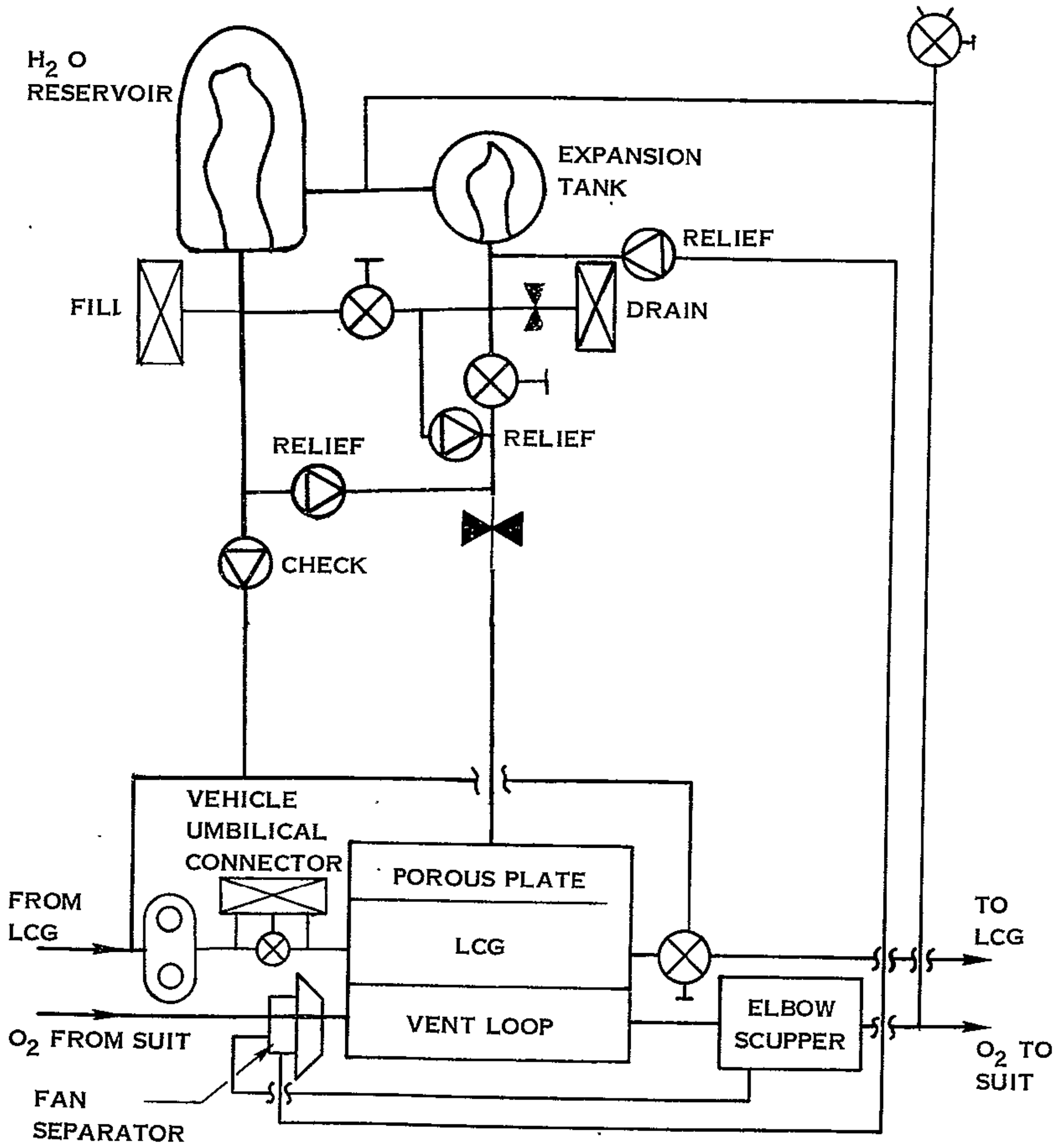
This concept is similar to Concept #3 except that the fan separator is replaced by a rotary separator directly driven by the ventilation loop fan separator for condensate transfer to the WMS. The necessary pressure drop to force flow into the secondary loop is accomplished by the head of the ventilation loop fan less the pressure drop of the sublimator and scupper.

Recharge is accomplished by utilization of the steps outlined in Concept #1.

A component weight and volume breakdown and the vehicle weight penalty for this concept are as follows:

Component	System Weight Kg (lbs)	System Volume (in^3) m^3
Primary Reservoir	1.0 (2.2)	(394) .00642
Expansion Tank	.36 (.8)	(75) .0012
H_2O	3.22 (7.1)	--
Dump Valve	.09 (.2)	(6) .000098
Fill Fitting	.045 (.1)	(3) .000049
Two Shutoffs	.18 (.4)	(12) .0002
Three Relief Valves	.14 (.3)	(3) .000049
Check Valve	.045 (.1)	(1) .000016
Pump	.59 (1.3)	(15) .00024
Vehicle Connector	.23 (.5)	(6) .000098
Rotary Separator	.09 (.2)	(5) .00008
Elbow Scupper	.14 (.3)	(8) .00013
Sublimator	1.59 (3.5)	(184) .003
TCV	.14 (.3)	(6) .000098
Drain Fitting	.045 (.1)	(3) .000049
Package	1.36 (3.0)	(80) .0013
Power Penalty		(42) .00068
Pump	.36 (.8)	
Rotary Separator	.18 (.4)	
Gas Delta P	.41 (.9)	
Total	10.2 (22.5)	(843) .014

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty= (32.8 Pounds) 14.9 Kg



CONCEPT 4. SUBLIMATOR, BUBBLE EXPANSION TANK, 1ST STAGE SCUPPER 2ND STAGE MOROR/ROTARY SEPARATOR

CONCEPT #5

This concept consists of a bubble expansion tank WMS, a three (3) fluid sublimator HRS, a first stage scupper/second stage elbow wick separator for condensate control and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

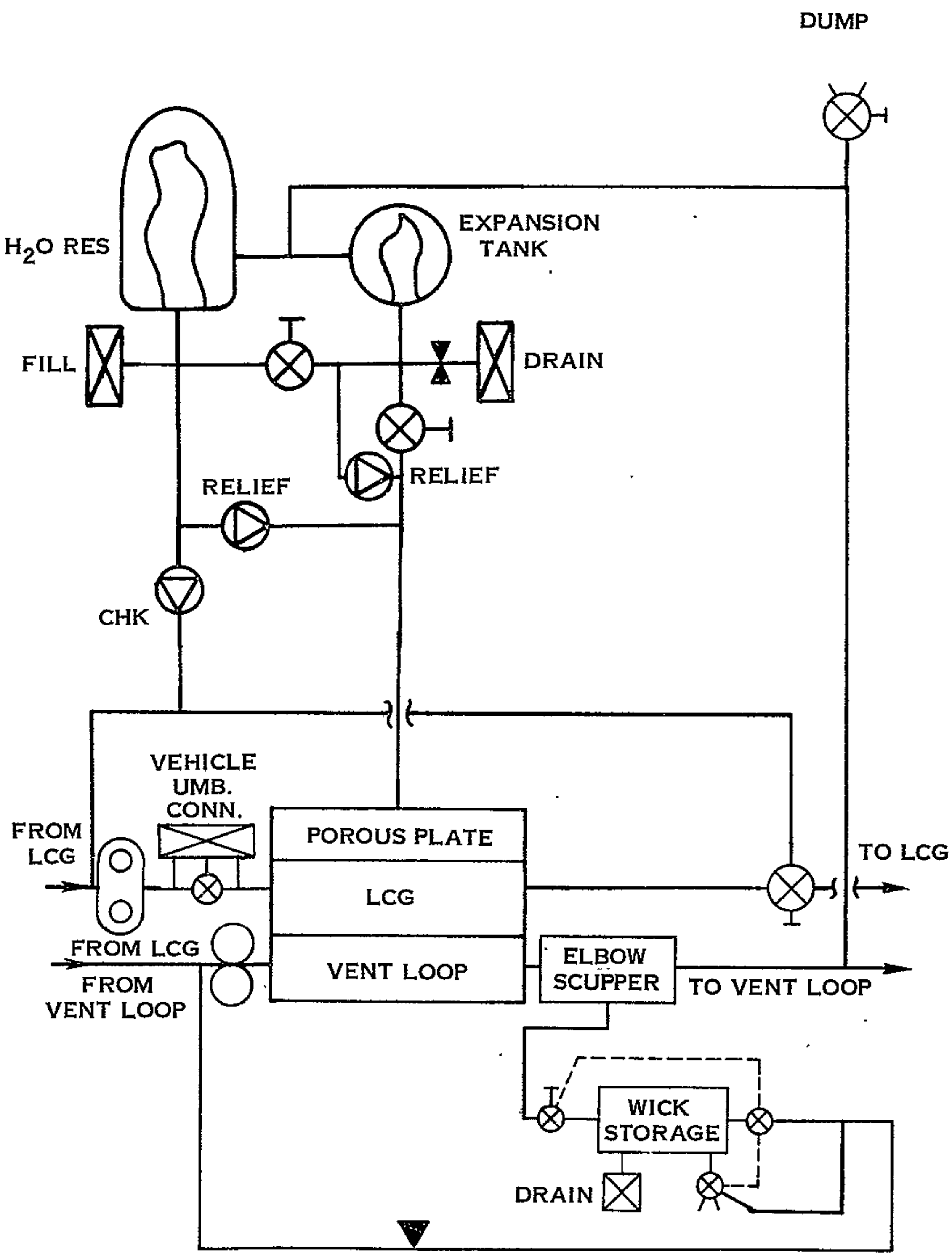
This concept is similar to Concept #4, except that the rotary separator is replaced by an elbow wick separator as described in Concept #2.

Recharge is accomplished by utilizing the steps outlined for Concept #2.

A component weight and volume breakdown and the vehicle weight penalty for this concept are as follows:

Component	System Weight Kg	(lbs)	System Volume (in^3)	m^3
Primary Reservoir	1.09	(2.4)	(446)	.0073
Expansion Tank	.36	(.8)	(85)	.0014
H_2O	3.68	(8.1)	--	
Dump Valve	.09	(.2)	(6)	.000098
Fill Fitting	.045	(.1)	(3)	.000049
Two Shutoffs	.18	(.4)	(12)	.0002
Two Relief Valves	.09	(.2)	(2)	.000033
Check Valves	.045	(.1)	(1)	.000016
Pump	.59	(1.3)	(15)	.00024
Vehicle Connector	.23	(.5)	(6)	.000098
Elbow Scupper	.14	(.3)	(8)	.00013
Elbow Wick Separator	1.14	(2.5)	(160)	.0026
3-In-1 Valve	.18	(.4)	(8)	.00013
Two Drain Fittings	.09	(.2)	(6)	.000098
Sublimator	1.59	(3.5)	(184)	.003
TCV	.14	(.3)	(6)	.000098
Package	1.54	(3.4)	(92)	.0015
Power Penalty			(34)	.00055
Pump	.36	(.8)		
Gas Delta P	.41	(.9)		
Total	12.0	(26.4)	(1,074)	.018

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (38.2 Pounds) 17.3 Kg



CONCEPT 5 - SUBLIMATOR, BUBBLE EXPANSION TANK, 1ST STAGE SCUPPER 2ND STAGE WICK STORAGE

CONCEPT #6

This concept consists of a bubble expansion tank WMS, a three (3) fluid sublimator HRS, a first stage slurper/stage rotary separator for condensate control and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

During operation, water enters from the LCG and is circulated by the pump, through the vehicle umbilical connector shutoff valve, the sublimator and the temperature control valve (TCV) and back to the LCG. The LCG water in the sublimator is the heat sink for the vent loop and is, in turn, cooled via heat transfer to the porous plate of the sublimator. During umbilical operation, the umbilical connector shutoff valve is closed routing all water to a heat exchanger in the vehicle which replaces the HRS heat sink. Thermal coolant control is achieved by the TCV which varies the water flow to the LCG. LCG pressurization and makeup water is supplied via the check valve between the feed water circuit and the LCG.

The vent loop flow coming from the suit is circulated by the fan through the LiOH canister and the vent loop portion of the sublimator/slurper.

Water separation is accomplished in two stages. Approximately three percent of the main stream flow is diverted through the slurper to the upstream side of the fan. The pressure differential between these two points continually drains the condensed water from the heat exchanger. The water/gas mixture enters the rotary separator which separates the water from the gas stream, and the gas is returned to the vent loop. The separated water is delivered to the feed water circuit through a relief valve which prevents the introduction of gas to the feed water circuit. The rotary separator is directly driven by the ventilation loop fan.

The expansion tank is sized to accept the gas released when the pressure in the main reservoir drops from 248 to 27.6 KPa (36 to 4 psia) and the water generated during one half hour of pre EVA umbilical operation; or, the tank will accommodate the water separated during a four and one half hours EVA in the non-venting mode.

Recharge of the system involves the following steps:

Open the shutoff valve between the two tanks.
Connect the drain fitting.
Open the EVLSS O_2 supply valve and hold.
Close the valve between the two tanks.
Close the O_2 supply valve.
Open the dump valve.
Connect the fill fitting and hold.
Disconnect the fill fitting.
Close the dump valve.

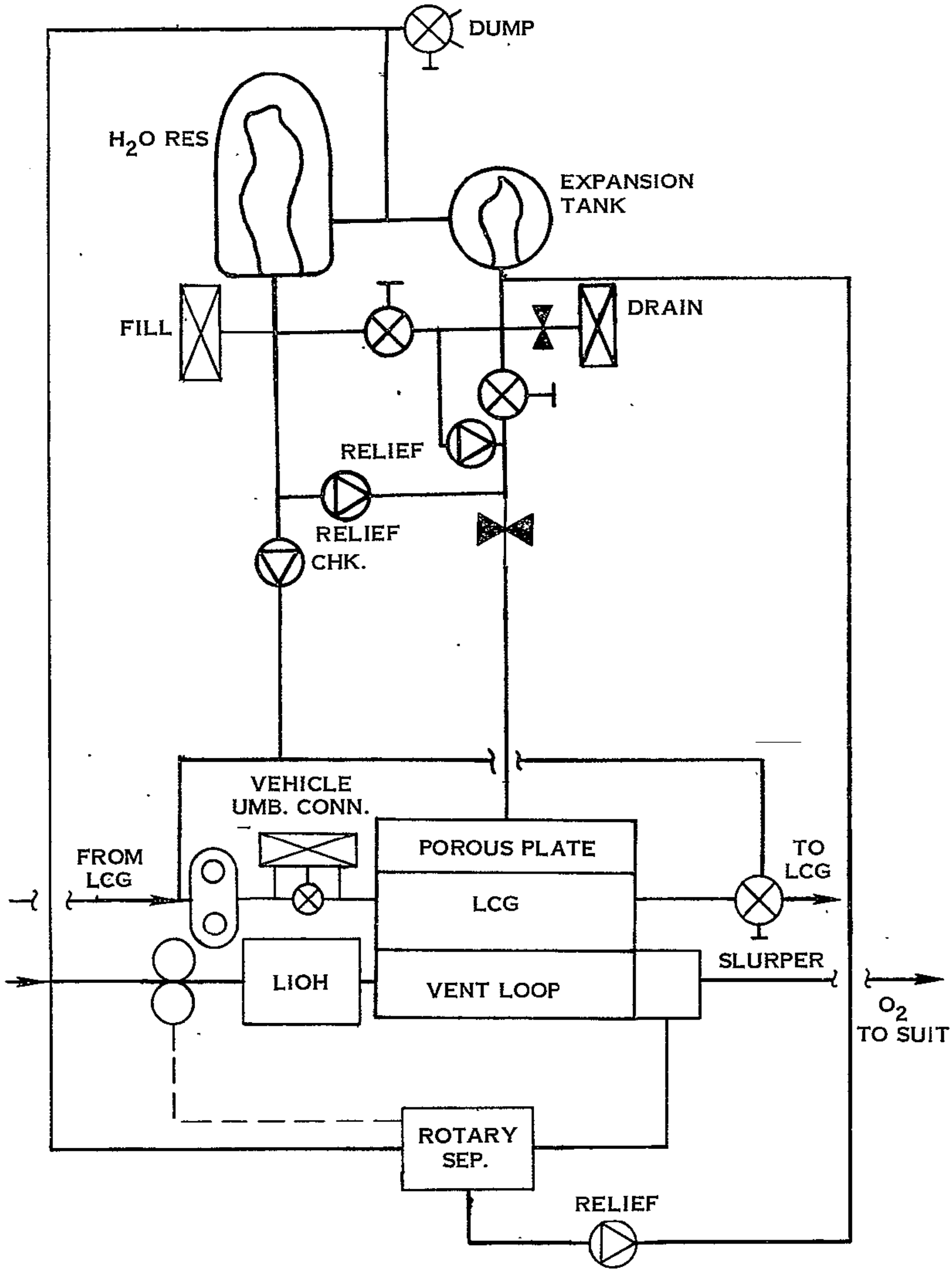
For normal EVA, the valve between the tanks is opened before donning the EVLSS, and the valve upstream of the porous plate is opened to activate the HRS. For non-venting EVA, both valves are left closed.

If the rotary separator relief valve were to fail open with the feed water lines dry and the shutoff valve open, the vent loop would exhaust directly to vacuum. The flow limiting orifice in the line to the sublimator was included to control gas leakage under these conditions.

A component weight and volume breakdown and the vehicle weight penalty for this concept are as follows:

Component	System Weight Kg (lbs)	System Volume (in^3) m^3
Primary Reservoir	1.04 (2.2)	(394) .00642
Expansion Tank	.36 (.8)	(75) .0012
H_2O	3.22 (7.1)	--
Dump Valve	.09 (.2)	(6) .000098
Fill Fitting	.045 (.1)	(3) .000049
Two Shutoffs	.18 (.4)	(12) .0002
Three Relief Valves	.14 (.3)	(3) .000049
Check Valve	.045 (.1)	(1) .000016
Pump	.59 (1.3)	(15) .000245
Vehicle Connector	.23 (.5)	(6) .000098
Sublimator	1.59 (3.5)	(184) .003
Slurper	.14 (.3)	(10) .00016
Rotary Separator	.36 (.2)	(5) .000082
TCV	.14 (.3)	(6) .000098
Package	1.32 (2.9)	(77) .00126
Drain Fitting	.045 (.1)	(3) .000049
Power Penalty		(29) .00047
Pump	.36 (.8)	
Rotary Separator	.18 (.4)	
Gas Delta P	.09 (.2)	
Total	9.85 (21.7)	(829) .014

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (30.5 Pounds) 13.9 Kg



CONCEPT 6 - SUBLIMATOR, BUBBLE EXPANSION TANK, 1ST STAGE SLURPER 2ND STAGE ROTARY SEPARATOR

CONCEPT #7

This concept consists of a bubble expansion tank WMS, a three (3) fluid sublimator HRS, a first stage slurper/second stage elbow wick separator for condensate control and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

This concept is similar to Concept #6, except that the rotary separator is replaced by an elbow wick separator which is sized to contain the water separated during a four and one half hour EVA. Since the separated water is stored and not utilized as feed water, the H_2O reservoir and expansion tank are larger than the tanks in Concept #6.

Recharge of the system involves the following steps.

Open the shutoff valve between the two tanks.
Connect drain lines to the drain connectors.
Close the three tier valve.
Open the EVLSS O_2 supply valve and hold.
Close the valve between the tanks.
Close the EVLSS O_2 supply valve.
Open the three tier valve.
Open the dump valve.
Connect the fill fitting and hold.
Disconnect the drain lines from the drain fittings.
Close the dump valve.

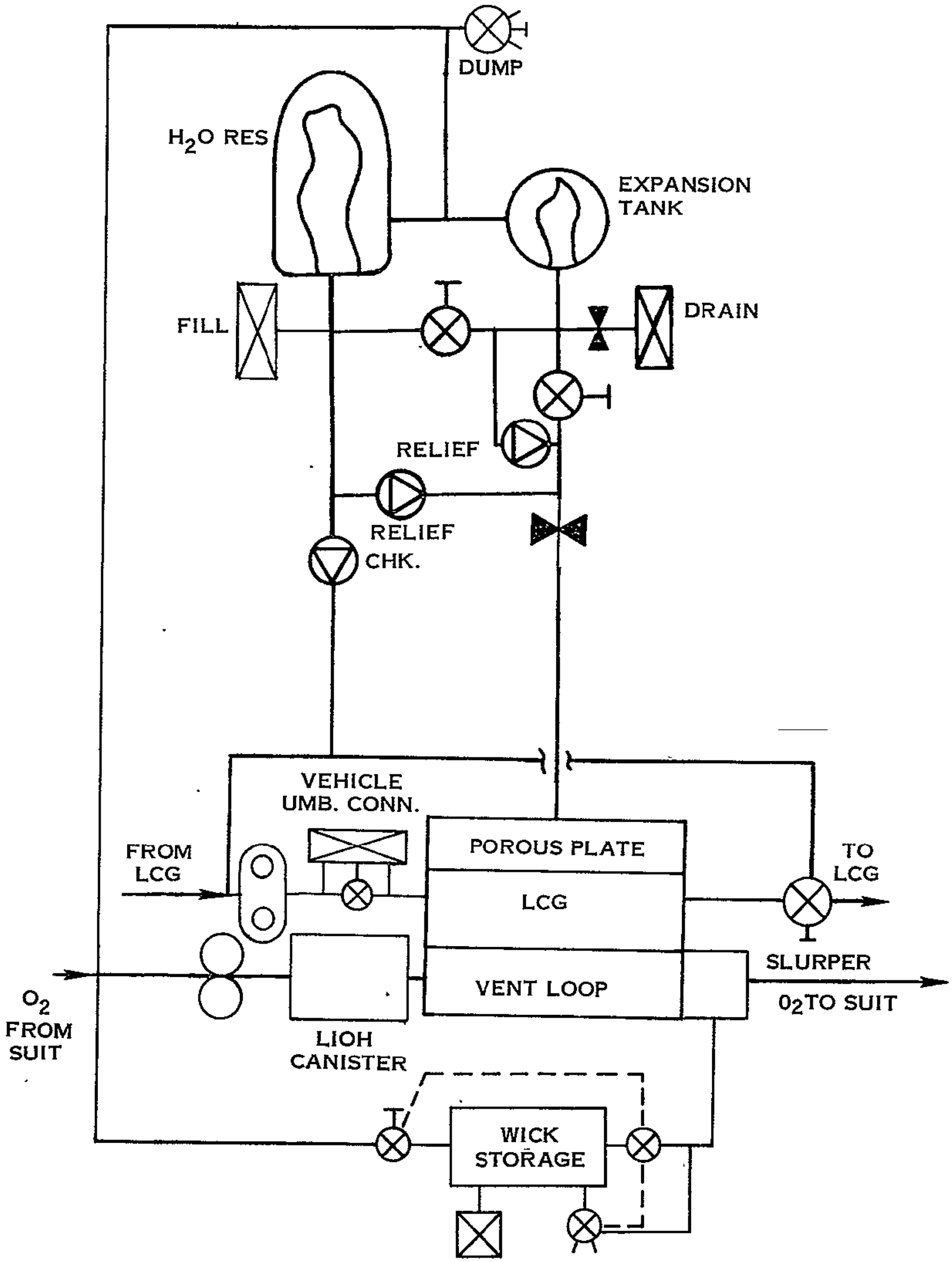
The backside of the bladder in the separator must be vented to vacuum during EVA; hence, failure of the bladder or the three tier valve could expose the vent loop to vacuum.

An orifice is incorporated in the three tier valve exhaust to control leakage in the event of bladder or valve failure.

A component weight and volume breakdown and the vehicle penalty for this concept are as follows:

Component	System Weight Kg	(lbs)	System Volume (in^3)	m^3
Primary Reservoir	1.09	(2.4)	(446)	.00727
Expansion Tank	.36	(.8)	(85)	.00139
H_2O	3.68	(8.1)	--	
Dump Valve	.09	(.2)	(6)	.000098
Fill Fitting	.045	(.1)	(3)	.000049
Two Shutoffs	.18	(.4)	(12)	.0002
Two Relief Valves	.09	(.2)	(2)	.000033
Check Valve	.045	(.1)	(1)	.000016
Pump	.59	(1.3)	(15)	.000245
Vehicle Connector	.23	(.5)	(6)	.000098
Sublimator	1.59	(3.5)	(184)	.003
Slurper	.14	(.3)	(10)	.00016
Elbow Wick Separator	1.14	(2.5)	(160)	.0026
Two Drain Fittings	.09	(.2)	(6)	.000098
3-In-1 Valve	.18	(.4)	(8)	.00013
TCV	.14	(.3)	(6)	.000098
Package	1.5	(3.3)	(92)	.0015
Power Penalty			(21)	.00034
Pump	.36	(.8)		
Gas Delta P	.09	(.2)		
Total	11.6	(25.6)	(1,063)	.017

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (36.0 Pounds) 16.3 Kg



CONCEPT 7 - SUBLIMATOR, S BUBBLE EXPANSION TANK, 1ST STAGE SLURPER 2ND STAGE WICK STORAGE

CONCEPT #8

This concept consists of a high pressure storage WMS, a three (3) fluid sublimator HRS, a single stage elbow wick separator for condensate control and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

During operation, water enters from the LCG and is circulated, by the EVLSS pump, through the vehicle umbilical connector shutoff valve, the sublimator, the temperature control (TCV) valve and back to the LCG. The LCG water in the sublimator is the heat sink for the vent loop and is, in turn, cooled via heat transfer to the porous plate of the sublimator. During umbilical operation, the umbilical connector shutoff valve is closed routing all water to a heat exchanger in the vehicle which replaces the porous plate heat sink. Thermal comfort control is achieved by the TCV which varies the water flow to the LCG. LCG pressurization and makeup water is supplied via a ground charged accumulator which is referenced to vent loop pressure.

The vent loop flow coming from the suit enters the sublimator where it is cooled below the dew point condensing water. The gas plus the condensed water enters the elbow wick separator which separates the condensed water from the gas stream, and the gas is then returned to the suit via the fan. When passing through the fan, the gas is super heated above the dew point to prevent visor fogging. The elbow wick separator is sized to contain all the water condensed during a four and one half hour EVA.

The feed water storage tank is pressurized by the EVLSS O_2 supply by two internal regulators. An orifice sized to handle regulator internal leakage is utilized downstream of the regulator to prevent over pressurization of the feed water reservoir by venting the regulators to the vent loop. A check valve, 227.5 KN/M^2 (33 psia) relief valve and manual valve system just upstream of the water tank is utilized to maintain tank pressure during water recharge. Two additional in line regulators are utilized downstream of the water reservoir to control feed water pressure to the sublimator porous plate at 27.6 KN/M^2 (4 psia).

Recharge of the system requires both draining the elbow wick separator and recharge of the water reservoir. This is accomplished by the following steps.

Closing the separator three tier valve.
Connect drain fitting.
Open the EVLSS O_2 system valve and hold.
Close the EVLSS O_2 system valve.
Open the relief valve shutoff valve.
Connect the vehicle fill line and hold.
Close the relief valve shutoff valve.
Disconnect the fill line.
Disconnect the drain fitting.
Open the separator three tier valve.

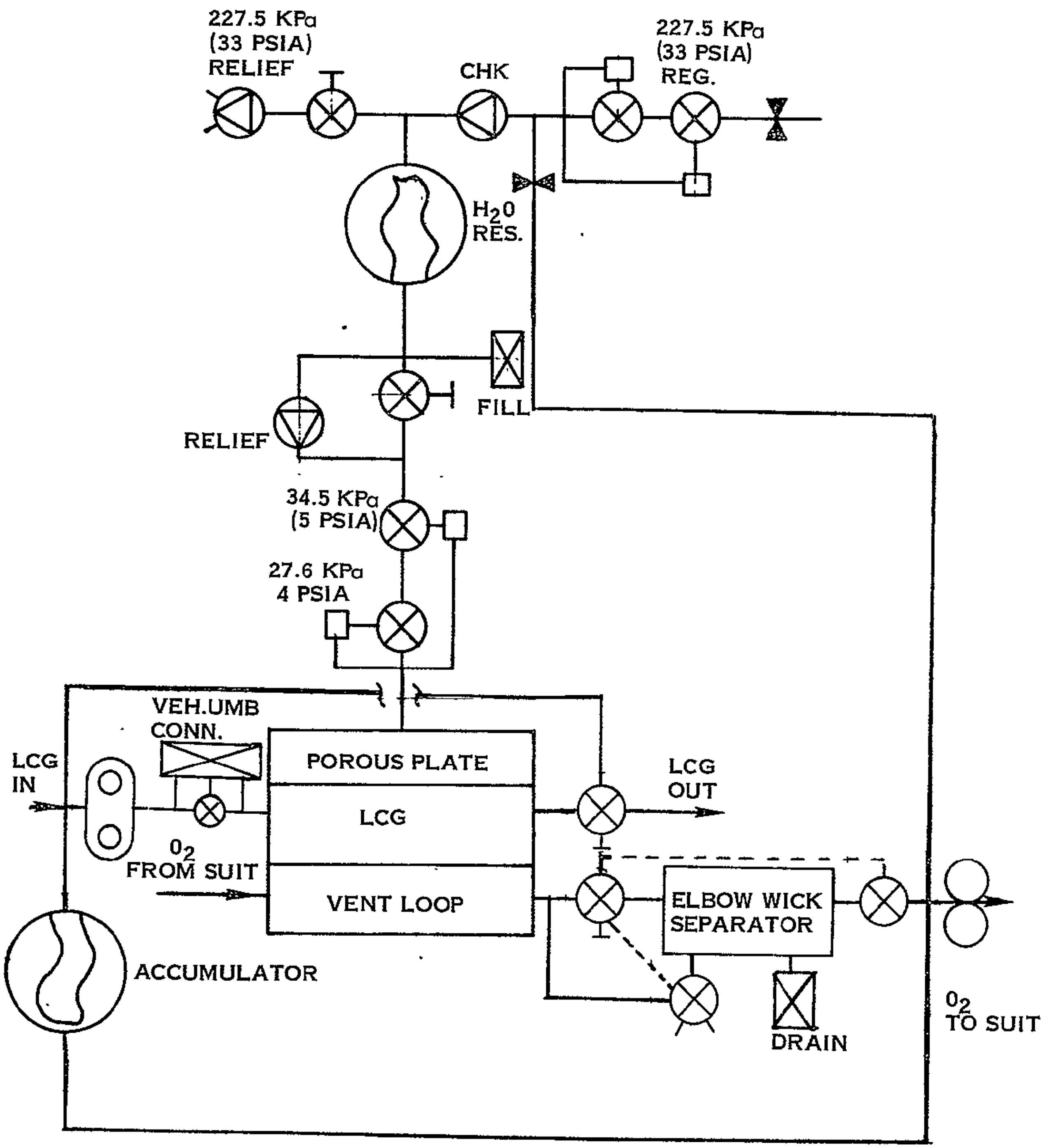
The backside of the bladder in the separator must be vented to vacuum during EVA; hence, failure of the bladder or the three tier valve could expose the vent loop to vacuum.

An orifice is incorporated in the three tier valve exhaust to control leakage in the event of bladder or valve failure.

A component weight and volume breakdown and the vehicle penalty of this concept are as follows:

Component	System Weight Kg	(lbs)	System Volume (in^3)	m^3
H_2O Reservoir	1.04	(2.3)	(432)	.007
H_2O	3.54	(7.8)	--	
O_2 Regulator	.23	(.5)	(4)	.000065
Check Valve	.045	(.1)	(1)	.000016
Two Shutoff Valves	.18	(.4)	(12)	.00020
Two Relief Valves	.09	(.2)	(2)	.000033
Fill Fitting	.045	(.1)	(3)	.00005
Two Water Regulators	.18	(.4)	(3)	.00005
Sublimator	1.59	(3.5)	(184)	.003
Pump	.59	(1.3)	(15)	.000245
Vehicle Connector	.23	(.5)	(6)	.000098
Accumulator H_2O	.32	(.7)	(20)	.000326
TCV	.14	(.3)	(6)	.000098
Elbow Wick Separator	1.14	(2.5)	(160)	.0026
3-In-1 Valve	.18	(.4)	(8)	.00013
Drain Fitting	.045	(.1)	(3)	.00005
Package	1.5	(3.3)	(83)	.00135
Power Penalty			(37)	.0006
Pump	.36	(.8)		
Gas Delta P	.5	(1.1)		
Total	11.9	(26.3)	(979)	.016

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (38.9 Pounds) 17.7 Kg



CONCEPT 8 - SUBLIMATOR, HIGH PRESSURE STORAGE, SINGLE STAGE ELBOW WICK SEPARATOR

CONCEPT #9

This concept consists of a high pressure storage WMS, a three (3) fluid sublimator, a first stage elbow scupper/second stage elbow wick separator condensate control system and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

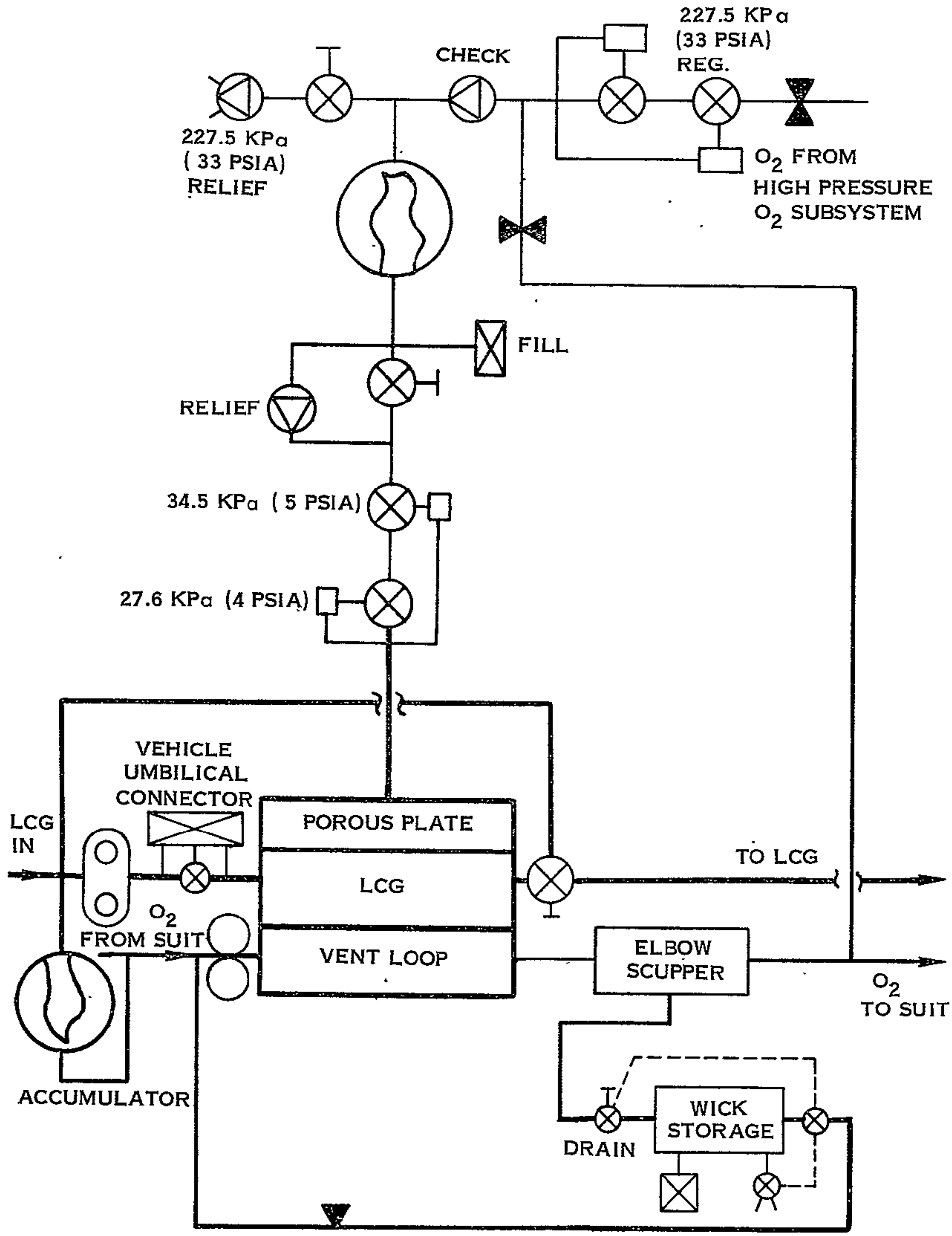
Operationally, this concept is similar to Concept #8, except humidity control is accomplished in two stages. The elbow scupper removes all the condensate and a small amount of gas from the main gas stream. The head of the ventilation loop fan less the pressure drop of the sublimator and scupper drives the separated water to the wick storage device.

Recharge is accomplished by utilization of the steps outlined for Concept #8.

The component weight and volume and vehicle weight penalty are as follows:

Component	System Weight Kg (lbs)	System Volume (in^3) m^3
H_2O Reservoir	1.04 (2.3)	(432) .007
H_2O	3.54 (7.8)	--
O_2 Regulator	.23 (.5)	(4) .000065
Check Valve	.045 (.1)	(1) .000016
Two Shutoff Valves	.18 (.4)	(12) .0002
Two Relief Valves	.09 (.2)	(2) .000032
Fill Fitting	.045 (.1)	(3) .00005
Two Water Regulators	.18 (.4)	(3) .00005
Sublimator	1.59 (3.5)	(184) .003
Pump	.59 (1.3)	(15) .000245
Vehicle Connector	.23 (.5)	(6) .000098
Accumulator + H_2O	.32 (.7)	(20) .00033
TCV	.14 (.3)	(6) .000098
Elbow Wick Separator	1.14 (2.5)	(160) .0026
3-In-1 Valve	.18 (.4)	(8) .00013
Drain Fitting	.045 (.1)	(3) .00005
Elbow Scupper	.14 (.3)	(8) .00013
Package	1.54 (3.4)	(84) .0014
Power Penalty		(34) .00055
Pump	.36 (.8)	
Gas Delta P	.41 (.9)	
Total	12.0 (26.5)	(985) .016

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (39.1 Pounds) 17.8 Kg



CONCEPT 9. SUBLIMATOR, HIGH PRESSURE STORAGE, 1ST STAGE SCUPPER 2ND STAGE WICK STORAGE

CONCEPT #10

This concept consists of a high pressure storage WMS, a three (3) fluid sublimator HRS, a first stage slurper/second stage wick separator for condensate control and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

During operation, water enters from the LCG and is circulated, by the EVLSS pump, through the vehicle umbilical connector shutoff valve, the sublimator, the temperature control valve (TCV) back to the LCG. The LCG water in the sublimator is the heat sink for the vent loop and is, in turn, cooled via heat transfer to the porous plate of the sublimator. During umbilical operation, the umbilical connector shutoff valve is closed routing all water to a heat exchanger in the vehicle which replaces the porous plate heat sink. Thermal comfort control is achieved by TCV which varies the water flow to the LCG. LCG pressurization and makeup water is supplied via a ground charged accumulator which is referenced to vent loop pressure.

The vent loop flow coming from the suit is circulated by the fan through the LiOH canister and the vent loop portion of the sublimator/slurper.

Water separation is accomplished in two stages. Approximately three percent of the main stream flow is directed through the slurper to the upstream side of the fan. The pressure differential between these two points continually drains the condensed water from the heat exchanger. The water/gas mixture enters the wick separator which separates the water from the gas stream and returns the gas to the vent loop. The elbow wick separator is sized to contain all the water condensed during a four and one half hour EVA.

The feed water storage tank is pressurized by the EVLSS O_2 supply by two internal regulators. An orifice sized to handle regulator internal leakage is utilized downstream of the regulator to prevent over pressurization of the feed water reservoir by venting the regulators to the vent loop. A check valve, 227.5 KN/M^2 (33 psia) relief valve and manual valve system just upstream of the water tank is utilized to maintain tank pressure during water recharge. Two additional in line regulators are utilized downstream of the water reservoir to control feed water pressure to the sublimator porous plate at 327.6 KN/M^2 (4 psia).

Recharge of the system requires both draining the elbow wick separator and recharge of the water reservoir. This is accomplished by the following steps.

Close the separator three tier valve.
Connect drain fitting.
Open the EVLSS O_2 system valve and hold.
Close the EVLSS O_2 system valve.
Open the relief valve shutoff valve.
Connect the vehicle fill line and hold.
Close the relief valve shutoff valve.

Disconnect the fill line.
Disconnect the drain fitting.
Open the separator three tier valve.

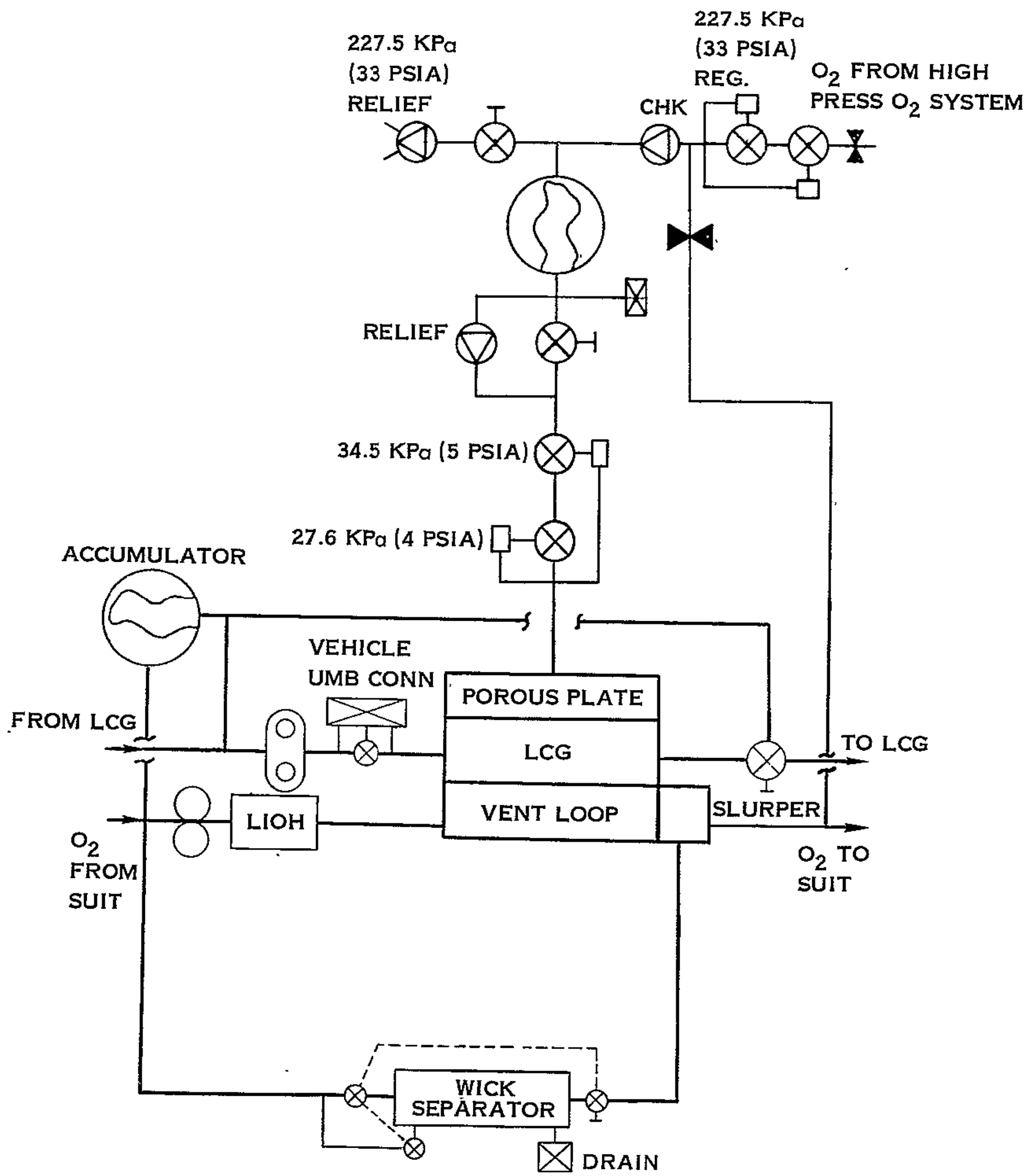
The backside of the bladder in the separator must be vented to vacuum during EVA; hence, failure of the bladder or the three tier valve could expose the vent loop to vacuum.

An orifice is incorporated in the three tier valve exhaust leakage in the event of bladder or valve failure.

A component weight and volume breakdown and the vehicle weight penalty for this concept are as follows:

Component	System Weight Kg	(lbs)	System Volume (in^3)	m^3
H_2O Reservoir	1.04	(2.3)	(432)	.007
H_2O	3.54	(7.8)		--
O_2 Regulator	.45	(1.0)	(8)	.00013
Check Valve	.045	(.1)	(1)	.000016
Two Shutoff Valves	.18	(.4)	(12)	.0002
Two Relief Valves	.09	(.2)	(2)	.000033
Fill Fitting	.045	(.1)	(3)	.00005
Two Water Regulators	.18	(.4)	(3)	.00005
Sublimator	1.36	(3.5)	(184)	.003
Slurper	.14	(.3)	(10)	.00016
Pump	.59	(1.3)	(15)	.000245
Vehicle Connector	.23	(.5)	(6)	.000098
Accumulator	.32	(.7)	(20)	.00033
TCV	.14	(.3)	(6)	.000098
Elbow Wick Separator	1.14	(2.5)	(160)	.0026
3-In-1 Valve	.18	(.4)	(8)	.00013
Drain Fitting	.045	(.1)	(3)	.00005
Package	1.50	(3.3)	(83)	.00135
Power Penalty			(21)	.00034
Pump	.36	(.8)		
Delta P	.09	(.2)		
Total	11.9	(26.2)	(975)	.016

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (37.8 Pounds) 17.2 Kg



CONCEPT 10 - SUBLIMATOR, HIGH PRESSURE STORAGE, 1ST STAGE
SLURPER 2ND STAGE WICK STORAGE

CONCEPT #11

This system consists of a bladder storage with pressure regulator WMS, a three (3) fluid sublimator HRS, a single stage elbow wick separator condensate control system and a vehicle umbilical connector to permit up to 4.5 hours of EVA with the HRS shutdown.

During operation, water enters from the LCG and is circulated, by the pump, through the vehicle umbilical connector shutoff valve, the sublimator, the temperature control valve TCV and back to the LCG. The LCG water in the sublimator is the heat sink for the vent loop and is, in turn, cooled via heat transfer to the porous plate of the sublimator. During umbilical operation, the umbilical connector shutoff valve is closed routing all water to a heat exchanger in the vehicle which replaces the porous plate heat sink. Thermal comfort control is achieved by the TCV which varies the water flow to the LCG. LCG pressurization and make up water is supplied via a ground charged accumulator which is referenced to suit pressure.

The vent loop flow coming from the suit enters the sublimator where it is cooled below the dew point condensing water. The gas plus the condensed water is processed by an elbow wick separator which separates the water from the gas stream, and the gas is then returned to the suit via the fan. When passing through the fan, the gas is super heated above the dew point to prevent visor fogging. The elbow wick separator is sized to contain all the water condensed during a four and one half hour EVA.

Feed water is fed to the sublimator through two in-line regulators.

Recharge of the system requires draining of both the elbow wick separator and the water reservoir as well as charging the reservoir.

This is accomplished by the following steps.

Close the separator three tier valve.
Connect drain lines to the drain connector and the fill connector.
Open the EVLSS O_2 supply valve and hold.
Disconnect the drain lines from the drain and fill connector.
Open the three tier valve.
Open the dump valve.
Connect fill line and hold.
Close the dump valve.
Disconnect the fill line.

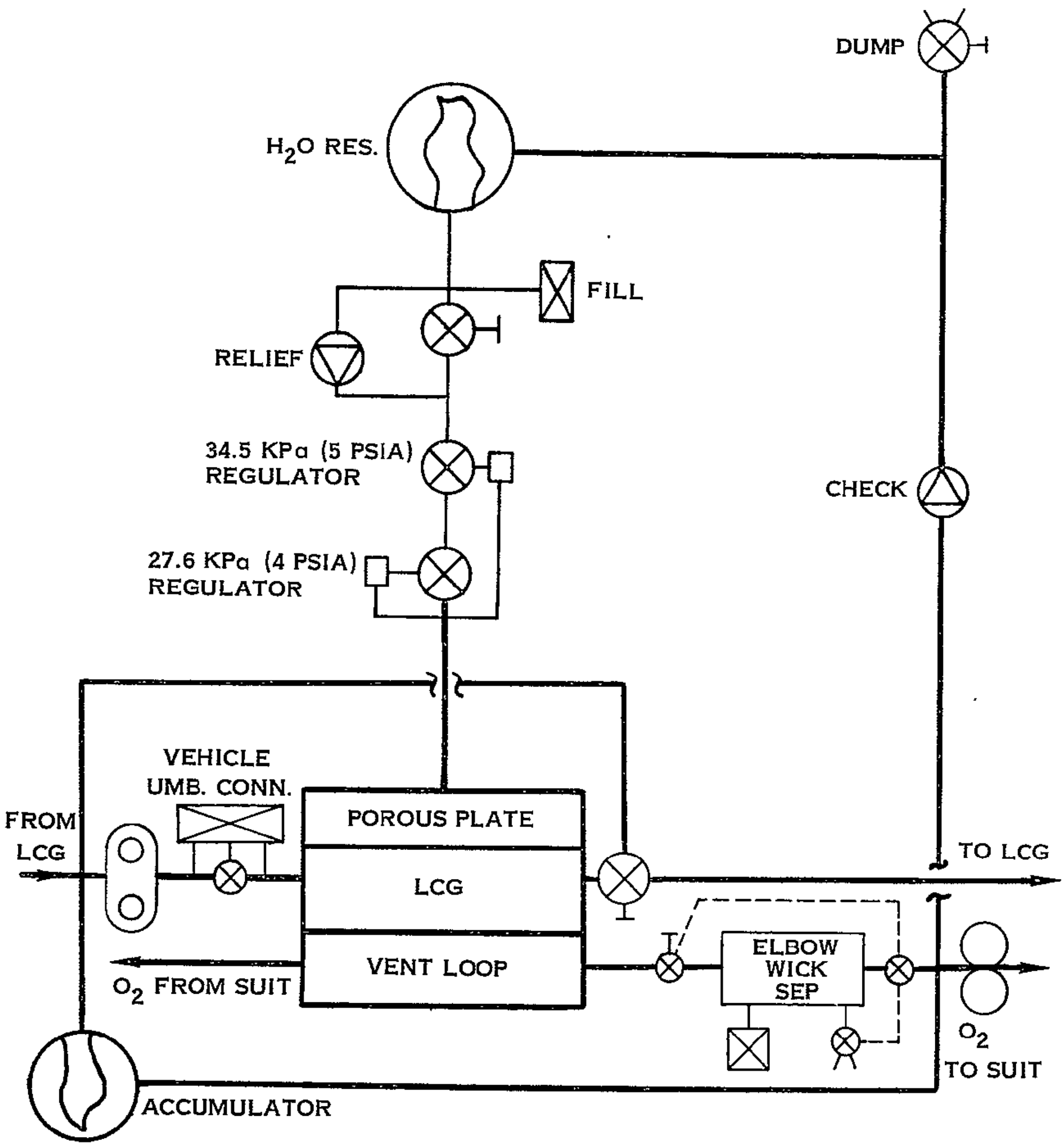
The backside of the bladder in the separator must be vented to vacuum during EVA; hence, failure of the bladder or the three tier valve could expose the vent loop to vacuum.

An orifice is incorporated in the three tier valve exhaust to control leakage in the event of bladder or valve failure.

A component weight and volume breakdown and the vehicle weight penalty are as follows:

Component	System Weight Kg (lbs)	System Volume (in^3) m^3
H_2O Reservoir	1.09 (2.4)	(446) .00727
H_2O	3.68 (8.1)	--
Dump Valve	.09 (.20)	(6) .000098
Shutoff Valve	.09 (.2)	(6) .000098
Relief Valve	.045 (.1)	(1) .000016
Fill Connector	.045 (.1)	(3) .00005
2 Water Regulators	.18 (.4)	(3) .00005
Sublimator	1.59 (3.5)	(184) .0003
Pump	.59 (1.3)	(15) .000245
Vehicle Umbilical Conn.	.23 (.5)	(6) .000098
Accumulator	.32 (.7)	(20) .00033
TCV	.14 (.3)	(6) .000098
Elbow Wick Separator	.91 (2.5)	(160) .00155
3-In-1 Valve	.18 (.4)	(8) .00013
Drain Fitting	.045 (.1)	(3) .00005
Package	1.5 (3.3)	(84) .00137
Power Penalty		(37) .0006
Pump	.36 (.8)	
Gas Delta P	.5 (1.1)	
Total	11.80 (26.0)	(988) .016

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (37.7 Pounds) 17.1 Kg



CONCEPT 11 - SUBLIMATOR, BLADDER STORAGE WITH PRESSURE REGULATOR, ELBOW WICK SEPARATOR

CONCEPT #12

This system consists of a bladder storage with pressure regulator WMS, a three (3) fluid sublimator HRS, a first stage elbow scupper/second stage elbow wick separator condensate control system and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the TCS shutdown.

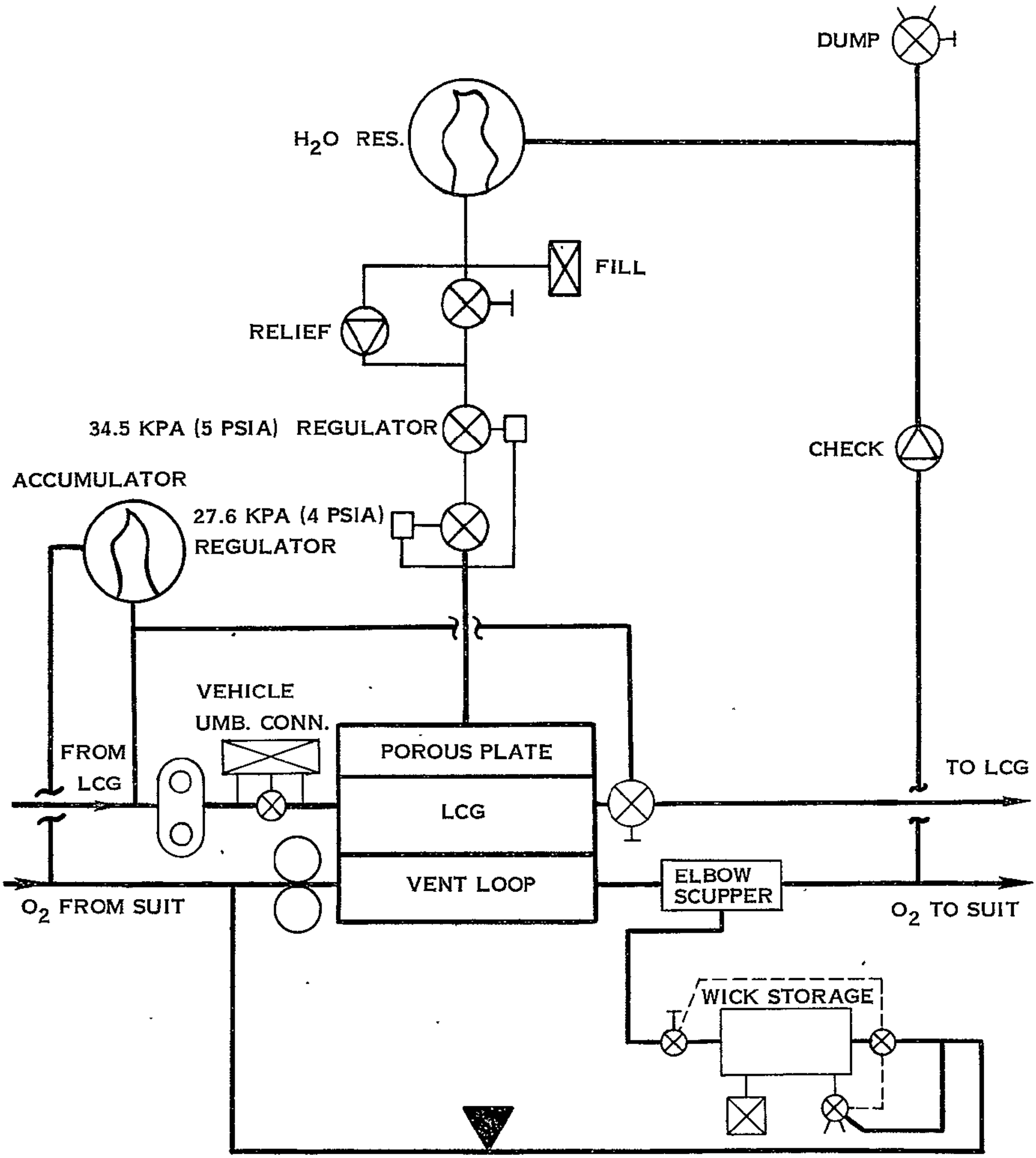
Operationally, this concept is similar to Concept #11, except humidity control is accomplished in two stages. The elbow scupper removes all the condensate and a small amount of gas from the main gas stream. The head of the ventilation loop fan less the pressure drop of the sublimator and scupper drives the separated water to the wick storage device.

Recharge is accomplished by utilizing the steps outlined for Concept #11.

A component weight and volume breakdown and the vehicle weight penalty are as follows:

Component	System Weight Kg (lbs)	System Volume (in^3) m^3
H_2O Reservoir	1.09 (2.4)	(446) .00727
H_2O	3.68 (8.1)	--
Dump Valve	.09 (.2)	(6) .000098
Shutoff Valve	.09 (.2)	(6) .000098
Relief Valve	.045 (.1)	(1) .000016
Fill Connector	.045 (.1)	(3) .00005
Two Water Regulators	.18 (.4)	(3) .00005
Sublimator	1.59 (3.5)	(184) .003
Pump	.59 (1.3)	(15) .000245
Vehicle Umbilical Conn.	.23 (.5)	(6) .000098
Accumulator	.32 (.7)	(20) .000326
TCV	.14 (.3)	(6) .000098
Elbow Wick Separator	1.14 (2.5)	(160) .0026
3-In-1 Valve	.18 (.4)	(8) .00013
Drain Fitting	.045 (.1)	(3) .00005
Elbow Scupper	.14 (.3)	(8) .00013
Package	1.54 (3.4)	(85) .00137
Power Penalty		(34) .00055
Pump	.36 (.8)	
Gas Delta P	.41 (.9)	
Total	11.9 (26.2)	(994) .016

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (37.9 Pounds) 17.2 Kg



CONCEPT 12— SUBLIMATOR, BLADDER STORAGE WITH PRESSURE REGULATOR, 1ST STAGE SCUPPER, 2ND STAGE WICK STORAGE

CONCEPT #13

This concept consists of a bladder storage with pressure regulator WMS, a three (3) fluid sublimator HRS, a first stage slurper/second stage elbow wick separator condensate control system and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

During operation, water enters from the LCG and is circulated, by the EVLSS pump, through the vehicle umbilical connector shutoff valve, the sublimator, the temperature control valve (TCV) and back to the LCG. The LCG water in the sublimator is the heat sink for the vent loop and is, in turn, cooled via heat transfer to the porous plate of the sublimator. During umbilical operation, the umbilical connector shutoff valve is closed routing all water to a heat exchanger in the vehicle which replaces the porous plate. Thermal comfort control is achieved by the TCV which varies the water flow to the LCG. LCG pressurization and makeup water is supplied via a ground charged accumulator which is referenced to suit pressure.

The vent loop flow coming from the suit is circulated by the fan through the LiOH canister and the vent loop portion of the sublimator/slurper.

Water separation is accomplished in two stages. Approximately three percent of the main stream flow passes from the slurper to the upstream side of the fan. The pressure differential between these two points continually drain the condensed water from the heat exchanger. The water/gas mixture enters the wick separator which separates the water from the gas stream, and the gas is returned to the vent loop. The elbow wick separator is sized to contain all the water condensed during a four and one half hour EVA.

Feed water is fed to the sublimator through two-in-line regulators.

Recharge of the system requires draining of both the elbow wick separator and the water reservoir as well as charging the reservoir. This involves the following steps:

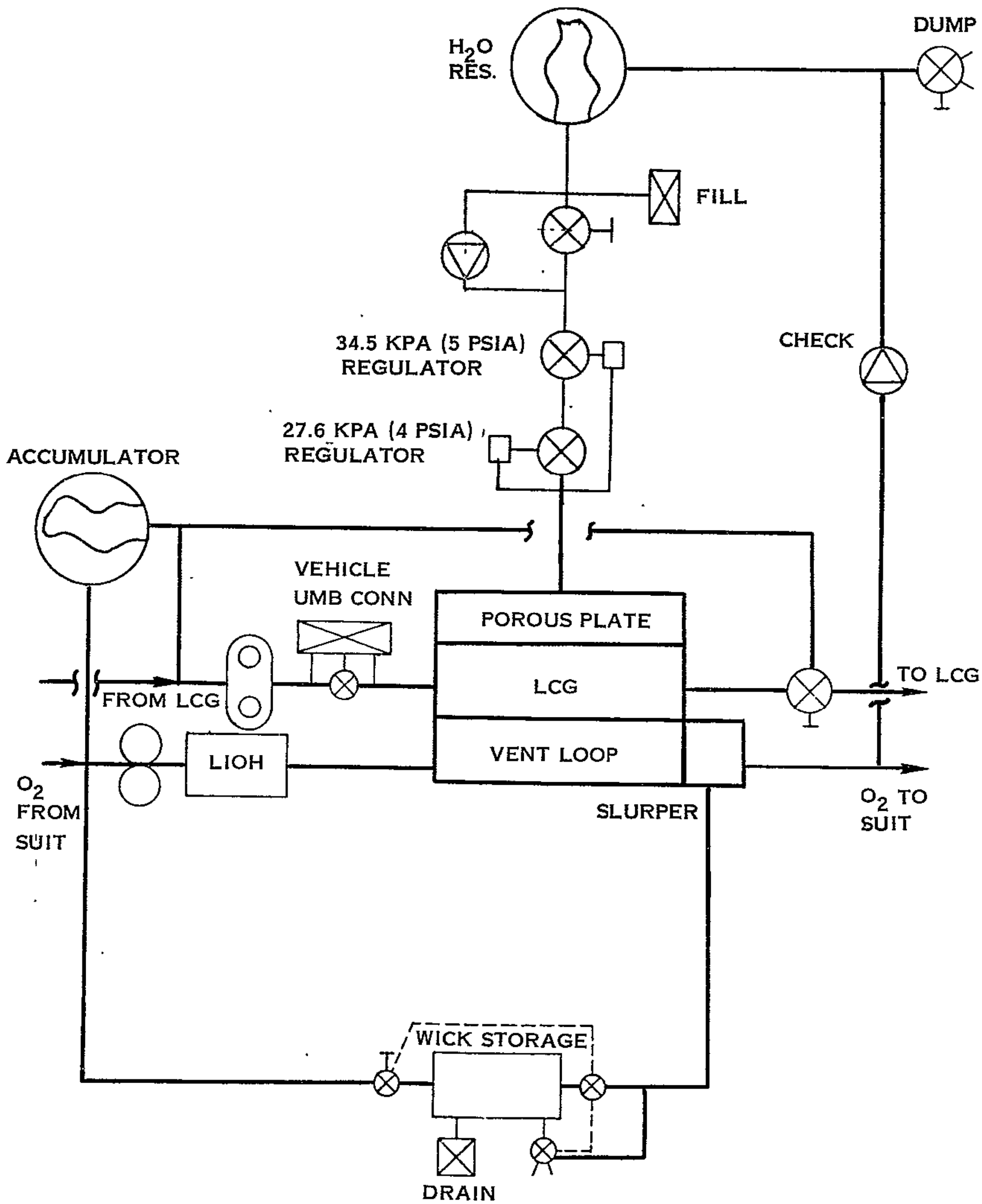
Close the separator three tier valve.
Connect drain line to the drain connector and the fill connector.
Open the EVLSS O_2 supply valve and hold.
Close the EVLSS O_2 supply valve.
Disconnect the drain line from the drain and fill connector.
Open the three tier valve.
Open the dump valve.
Connect fill line and hold.
Close the dump valve.
Disconnect the fill line.

The backside of the bladder in the separator must be vented to vacuum during EVA; hence, failure of the bladder or the three tier valve could expose the vent loop to vacuum. An orifice is incorporated in the three tier valve exhaust to control leakage in the event of bladder or valve failure.

A component weight and volume breakdown and the vehicle weight penalty are as follows:

Component	System Weight Kg (lbs)	System Volume (in^3) m^3
H_2O Reservoir	1.09 (2.4)	(446) .00727
H_2O	3.68 (8.1)	--
Dump Valve	.09 (.2)	(6) .000098
Shutoff Valve	.09 (.2)	(6) .000098
Relièf Valve	.045 (.1)	(1) .000016
Fill Connector	.045 (.1)	(3) .00005
2 Water Regulators	.18 (.4)	(3) .00005
Sublimator	1.59 (3.5)	(184) .003
Pump	.59 (1.3)	(15) .000245
Vehicle Umbilical Conn.	.23 (.5)	(6) .000098
Accumulator	.32 (.7)	(20) .000326
TCV	.14 (.3)	(6) .000098
Elbow Wick Separator	.91 (2.5)	(160) .0026
3-In-1 Valve	.18 (.4)	(8) .00013
Drain Fitting	.045 (.1)	(3) .00005
Slurper	.14 (.3)	(10) .00016
Package	1.50 (3.30)	(84) .00137
Power Penalty		(21) .000342
Pump	.36 (.8)	
Gas Delta P	.09 (.2)	
Total	11.5 (25.4)	(982) .016

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (35.6 Pounds) 16.2 Kg



CONCEPT 13- SUBLIMATOR, BLADDER STORAGE WITH PRESSURE REGULATOR, 1ST STAGE SLURPER, 2ND STAGE WICK STORAGE

CONCEPT #14

This concept consists of a high pressure storage WMS, a two-two fluid flash evaporator, a single stage elbow wick separator and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

During operation, water enters from the LCG and is circulated by the pump through the vehicle umbilical connector shutoff valve, the flash evaporator, the vent loop to LCG HX, the temperature control valve (TCV) and back to the LCG. The LCG water is cooled in the flash evaporator and, in turn, the LCG water cools the vent loop O_2 via the vent loop to LCG HX. During umbilical operation, the umbilical connector shutoff valve is closed routing all water to a heat exchanger in the vehicle which replaces the flash evaporator heat sink. Thermal comfort control is achieved by the TCV which varies the water flow to the LCG. LCG pressurization and makeup water is supplied via a ground charged accumulator which is referenced to suit pressure.

The vent loop flow coming from the suit enters the condensing heat exchanger where it is cooled below the dew point. The gas plus the condensed water enters the elbow wick separator which separates the water from the gas stream which is then returned to the suit via the fan. When passing through the fan, the gas is super heated above the dew point to prevent visor fogging. The elbow wick separator is sized to contain all the water condensed during a four and one half hour EVA.

The feed water storage tank is pressurized by the EVLSS O_2 supply by two in-line regulators. An orifice sized to handle regulator internal leakage is utilized downstream of the regulator to prevent over pressurization of the feed water reservoir by venting the regulators to the vent loop. A check valve, 227.5 KN/M^2 (33 psia) relief valve and manual valve system just upstream of the water tank is utilized to maintain tank pressure during water recharge.

Recharge of the system requires both draining the elbow wick separator and recharge of the water reservoir. This is accomplished by utilizing the following:

Close the separator three tier valve.
Connect drain fitting.
Open the EVLSS O_2 system valve and hold.
Close the EVLSS O_2 system valve.
Open the relief valve shutoff valve.
Connect the vehicle fill line and hold.
Close the relief valve shutoff valve.
Disconnect the fill line.
Disconnect the drain fitting.
Open the separator three tier valve.

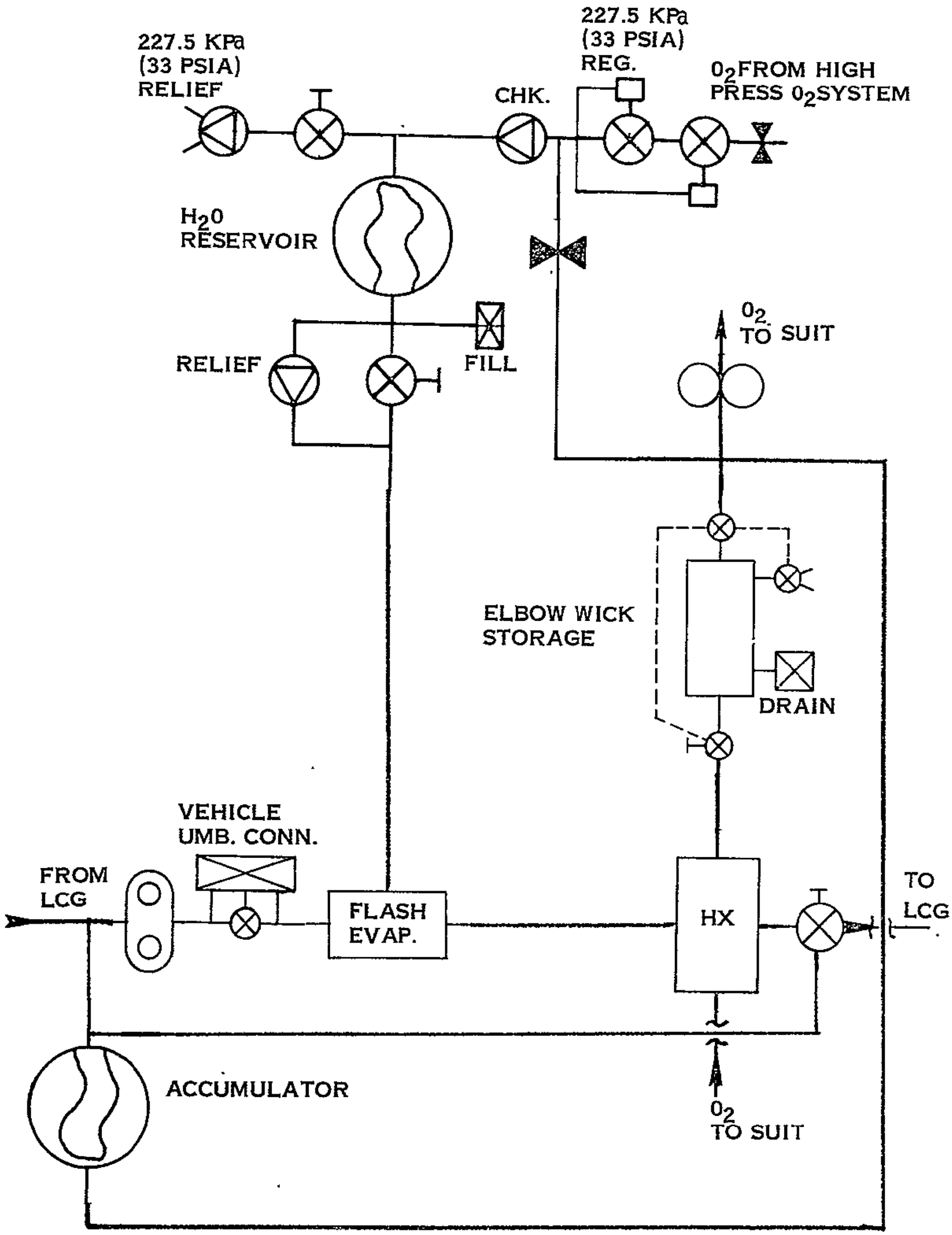
The backside of the bladder in the separator must be vented to vacuum during EVA; hence, failure of the bladder or the three tier valve could expose the vent loop to vacuum.

An orifice is incorporated in the three tier valve exhaust to control leakage in the event of bladder or valve failure.

The component weight and volume and the vehicle weight penalty are as follows:

Component	System Weight Kg	(lbs)	System Volume (in^3)	m^3
H_2O Reservoir	1.09	(2.4)	(457)	.00745
H_2O	3.77	(8.3)	--	
O_2 Regulator	.454	(1.0)	(8)	.00013
Check Valve	.045	(.1)	(1)	.000016
Two Shutoff Valves	.18	(.4)	(12)	.0002
Two Relief Valves	.09	(.2)	(2)	.000033
Fill Fitting	.045	(.1)	(3)	.00005
Flash Evaporator	1.09	(2.4)	(196)	.0032
HX	.36	(.8)	(10)	.000163
Controller	.68	(1.5)	(40)	.00065
Pump	.59	(1.3)	(15)	.000245
Vehicle Connector	.23	(.5)	(6)	.000098
Accumulator + H_2O	.32	(.7)	(20)	.000326
TCV	.14	(.3)	(6)	.000098
Elbow Wick Separator	1.14	(2.5)	(160)	.0026
3-In-1 Valve	.18	(.4)	(6)	.000098
Drain Fitting	.045	(.1)	(3)	.00005
Package	1.63	(3.6)	(92)	.0015
Power Penalty			(45)	.00073
Pump	.36	(.8)		
Gas Delta P	.5	(1.1)		
Controller and Solenoid	.18	(.4)		
Total	13.1	(28.9)	(1,082)	.018

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (43.5 Pounds) 19.7 Kg



CONCEPT 14 — FLASH EVAPORATOR, HIGH PRESSURE STORAGE, SINGLE STAGE ELBOW WICK SEPARATOR

CONCEPT #15

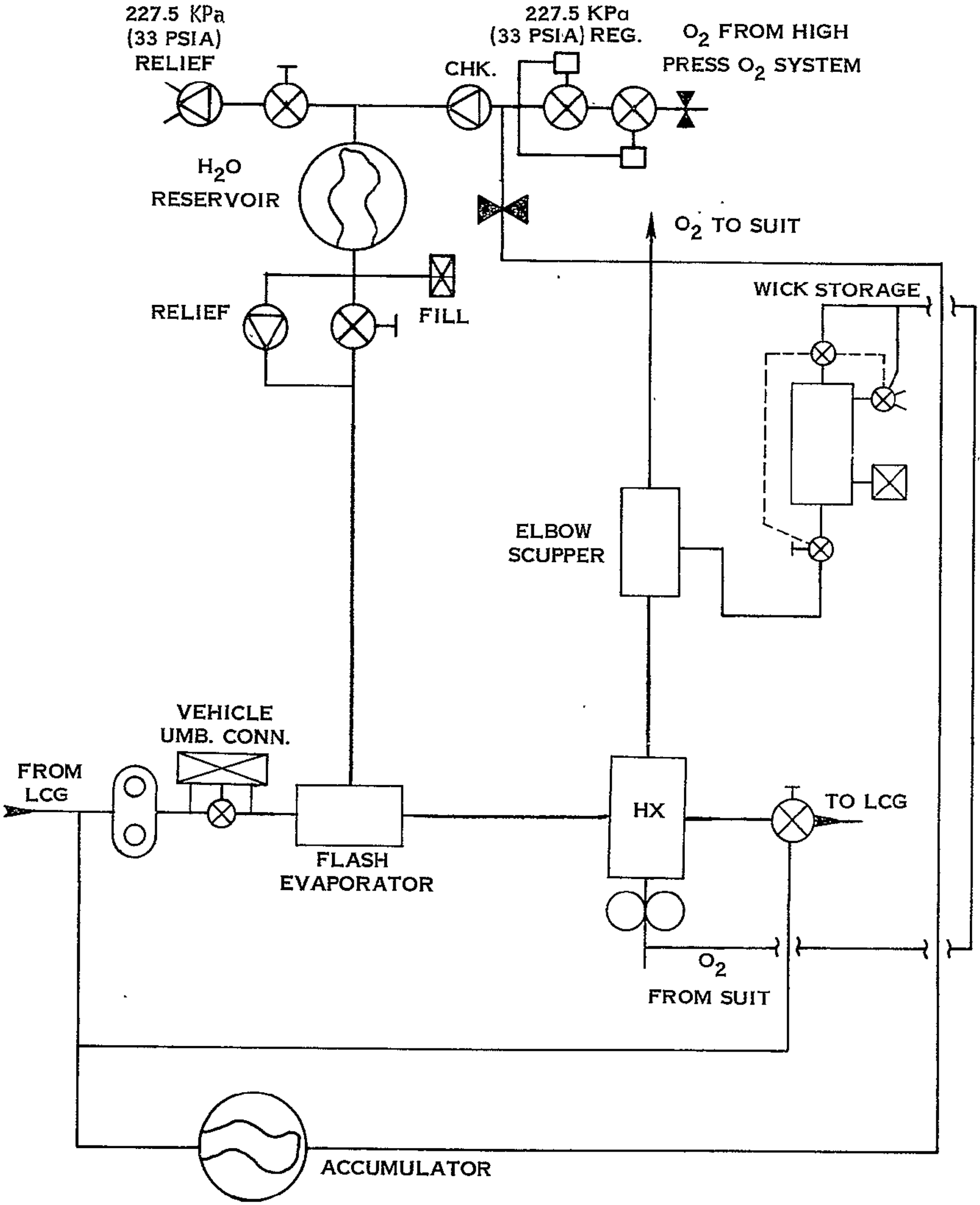
This concept consists of a high pressure storage WMS, a two-two fluid flash evaporator HRS, a first stage elbow scupper/second stage elbow wick separator condensate control system and a vehicle umbilical connector to permit 4.5 hours of umbilical operation with the HRS shutdown.

Operationally, this concept is similar to Concept #14, except humidity control is accomplished in two stages. The elbow scupper removes all the condensate and a small amount of gas from the main gas stream. The head of the ventilation loop fan less the temperature of heat exchanger and the scupper creates the pressure differential necessary to drive the separated water to the wick storage device.

Recharge is accomplished by utilizing the steps outlined for Concept #14.

Component	System Weight Kg (lbs)	System Volume (in^3) m^3
H_2O Reservoir	1.09 (2.4)	(457) .00745
H_2O	3.77 (8.3)	--
Two O_2 Regulators	.454 (1.0)	(8) .00013
Check Valve	.045 (.1)	(1) .000016
Two Shutoff Valves	.18 (.4)	(12) .0002
Two Relief Valves	.09 (.2)	(2) .00003
Fill Fittings	.045 (.1)	
Flash Evaporator	1.09 (2.4)	(196) .0032
Heat Exchanger	.36 (.8)	(10) .00016
Controller	.68 (1.5)	(40) .00065
Pump	.59 (1.3)	(15) .000245
Vehicle Connector	.23 (.5)	(6) .000098
TCV	.14 (.3)	(6) .000098
Elbow Wick Separator	1.14 (2.5)	(160) .0026
Accumulator	.32 (.7)	(20) .00033
3-In-1 Valve	.18 (.4)	(8) .00013
Drain Fitting	.045 (.1)	(3) .00005
Elbow Scupper	.14 (.3)	(8) .00013
Package	1.68 (3.7)	(92) .0015
Power Penalty		(42) .00068
Pump	.36 (.8)	
Gas Delta P	.41 (.9)	
Controller	.18 (.4)	
Total	13.3 (29.2)	(1,090) .018

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (43.9 Pounds) 19.9 Kg



CONCEPT 15 — FLASH EVAPORATOR, HIGH PRESSURE STORAGE, 1ST STAGE SCUPPER 2ND STAGE WICK STORAGE

CONCEPT #16

This concept consists of high pressure storage WMS, a two-two fluid flash evaporator, a first stage slurper/second stage elbow wick separator and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

During operation, water enters from the LCG and is circulated, by the pump, through the vehicle umbilical connector shutoff valve, the flash evaporator, the vent loop to LCG HX, the temperature control valve (TCV) and back to the LCG. The LCG water is cooled in the flash evaporator and, in turn, the LCG water cools the vent loop O_2 via the vent loop to LCG HX.

During umbilical operation, the umbilical connector shutoff valve is closed routing all water to a heat exchanger in the vehicle which replaces the flash evaporator heat sink. Thermal comfort control is achieved by the TCV which varies the water flow to the LCG. LCG pressurization and makeup water is supplied via a ground charged accumulator which is referenced to vent loop pressure.

The vent loop flow coming from the suit is circulated by the fan through the LiOH canister and the vent loop to LCG heat exchanger/slurper.

Water separation is accomplished in two stages. Approximately three percent of the main stream flow passes from the slurper to the upstream side of the fan. The pressure differential between these two points continually drains the condensed water from the heat exchanger. The water/gas mixture passes to the wick separator which separates the water from the secondary gas stream.

The feed water storage tank is pressurized by the EVLSS O_2 supply by two in-line regulators. An orifice sized to handle regulator internal leakage is utilized downstream of the regulator to prevent over pressurization of the feed water reservoir by venting the regulator to the vent loop. A check valve, 227.5 KN/M^2 (33 psia) relief valve and manual valve system just up-stream of the water tank is utilized to maintain tank pressure during water recharge.

Recharge of the system requires both draining the elbow wick separator and recharge of the water reservoir. This is accomplished by utilizing the following steps:

Close the separator three tier valve.
Connect drain fitting.
Open the EVLSS O_2 system valve and hold.
Close the EVLSS O_2 system valve.
Open the relief valve shutoff valve.
Connect the vehicle fill line and hold.

Close the relief valve shutoff valve.
Disconnect the fill line.
Disconnect the drain fitting.
Open the separator three tier valve.

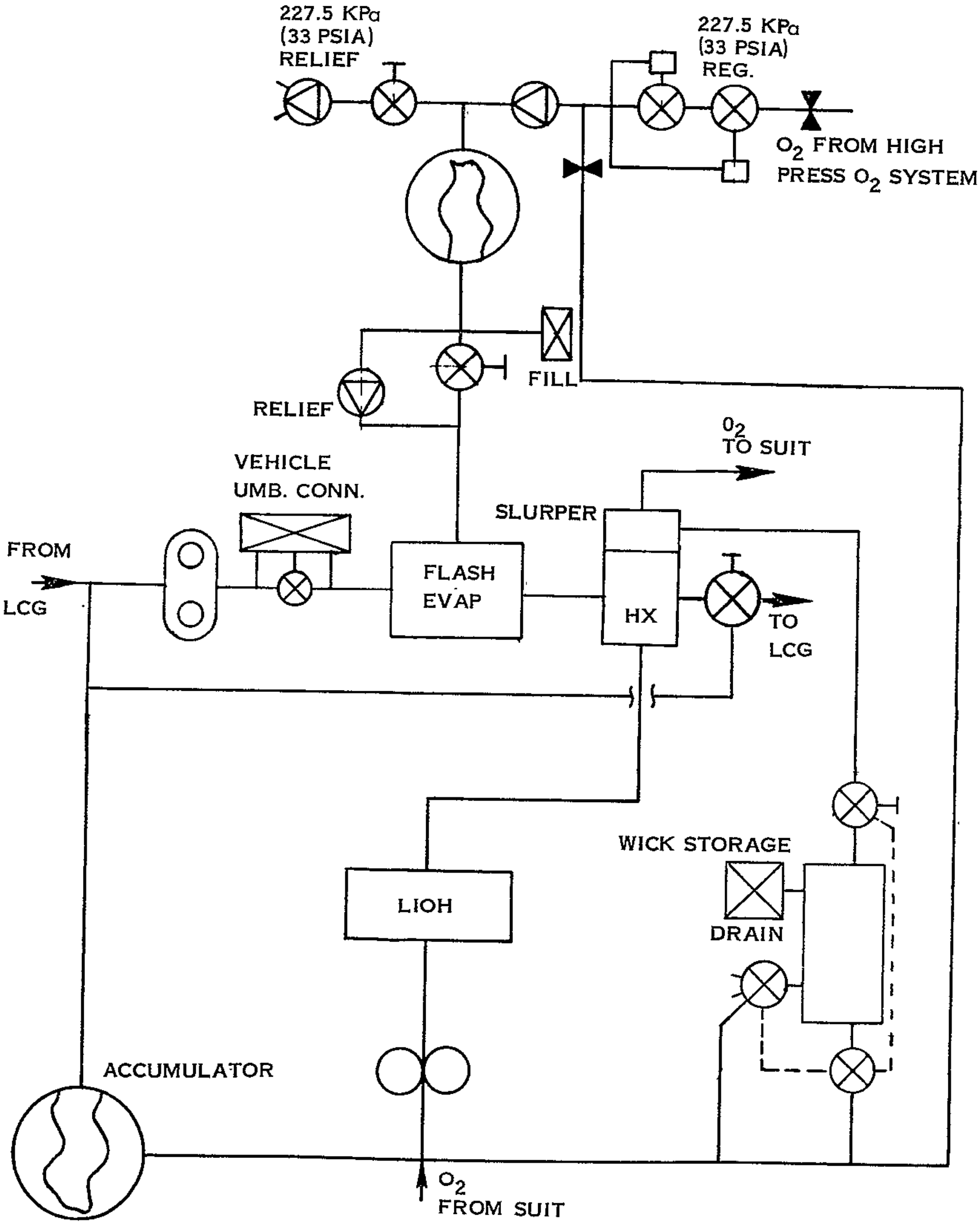
The backside of the bladder in the separator must be vented to vacuum during EVA; hence, failure of the bladder or the three tier valve could expose the vent loop to vacuum.

An orifice is incorporated in the three tier valve exhaust to control leakage in the event of bladder or valve failure.

A component weight and volume breakdown are as follows:

Component	System Weight Kg (lbs)	System Volume (in^3) m^3
H_2O Reservoir	1.09 (2.4)	(457) .00745
H_2O	3.77 (8.3)	--
Two O_2 Regulators	.454 (1.0)	(8) .00013
Check Valves	.045 (.1)	(1) .000016
Two Shutoff Valves	.18 (.4)	(12) .0002
Two Relief Valves	.09 (.2)	(2) .000033
Fill Fittings	.045 (.1)	(3) .00005
Flash Evaporator	1.09 (2.4)	(196) .0032
Heat Exchanger	.36 (.8)	(10) .00016
Slurper	.14 (.3)	(10) .00016
Controller	.68 (1.5)	(40) .00065
Pump	.59 (1.3)	(15) .000245
Vehicle Connector	.23 (.5)	(6) .000098
TCV	.14 (.3)	(6) .000098
Elbow Wick Separator	.91 (2.5)	(160) .0026
Accumulator	.32 (.7)	(20) .00033
3-In-1 Valve	.18 (.4)	(8) .00013
Drain Fitting	.045 (.1)	(3) .00005
Package	1.68 (3.7)	(94) .0015
Power Penalty		(42) .00068
Pump	.36 (.8)	
Gas Delta P	.09 (.2)	
Controller	.18 (.4)	
Total	12.9 (28.4)	(1,093) .018

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (41.6 Pounds) 18.9 Kg



CONCEPT 16. FLASH EVAPORATOR, HIGH PRESSURE STORAGE, 1ST STAGE SLURPER, 2ND STAGE WICK STORAGE

CONCEPT #17

This concept consists of a bubble expansion tank WMS, a three (3) fluid sublimator HRS, a first stage elbow wick separator (30 minute capacity) and a vehicle umbilical connector to permit 30 minutes of umbilical operation with the HRS shutdown.

During operation, water enters from the LCG and is circulated, by the EVLSS pump, through the vehicle umbilical connector shutoff valve, the sublimator, the temperature control valve TCV and is routed back to the LCG. The LCG water in the sublimator is the heat sink for the vent loop and is, in turn, cooled via heat transfer to the porous plate region of the sublimator. During umbilical operation, the umbilical connector shutoff valve is closed routing all water to a heat exchanger in the vehicle which replaces the porous plate heat sink. Thermal comfort control is achieved by the TCV which varies the water flow to the LCG. LCG pressurization and make up water is supplied via a ground charged accumulator which is referenced to suit pressure.

The vent loop flow coming from the suit enters the sublimator where it is cooled below the dew point condensing water. The gas plus the condensed water enters the elbow wick separator which separates the condensed water from the gas stream, and the gas is then returned to the suit via the fan. When passing through the fan, the gas is super heated above the dew point to prevent visor fogging. The elbow wick separator is sized to contain the water condensed during one half hour of umbilical operation.

At the end of the half hour umbilical operation, the HRS is activated drawing water from the reservoir. The pressure differential between the separator and the collapsing bladder draws the separated water to the back side of the bladder.

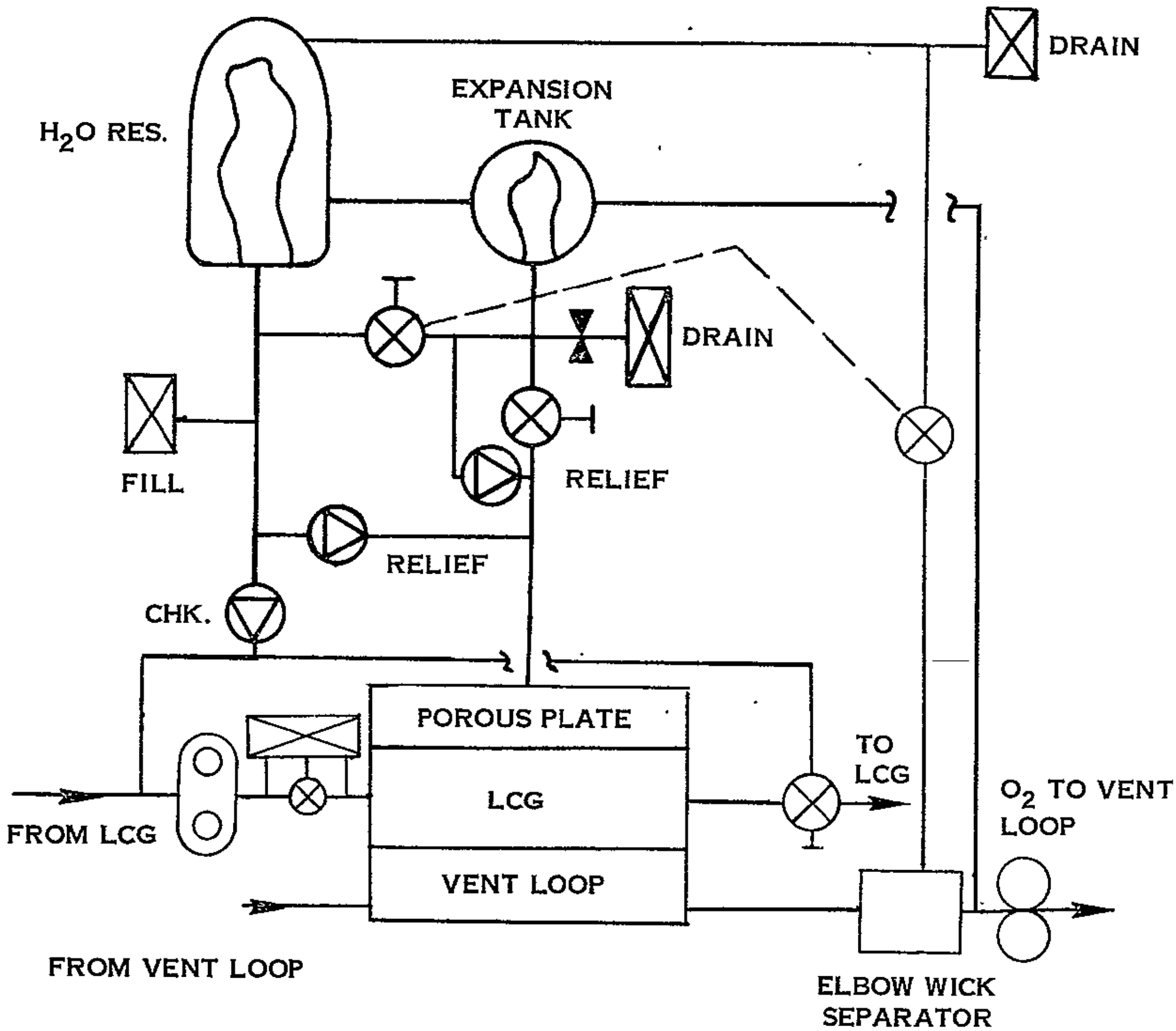
Recharge of the system involves the following steps:

Open the shutoff valve between the two tanks.
Connect the drain fitting.
Open the EVLSS O_2 supply valve and hold.
Close the valve between the two tanks.
Close the O_2 supply valve.
Open the dump valve.
Connect the fill fitting and hold.
Disconnect the fill fitting.
Close the dump valve.

The component weight and volume breakdown and the vehicle weight penalty are as follows:

Component	System Weight Kg	(lbs)	System Volume (in^3)	m^3
H_2O Reservoir	1.09	(2.4)	(446)	.00727
H_2O	3.68	(8.1)		--
Vehicle Umbilical Conn.	.23	(.5)	(6)	.000098
Fill Fitting	.045	(.1)	(3)	.00005
Drain Fitting	.045	(.1)	(3)	.00005
Two Shutoff Valve	.18	(.4)	(6)	.000098
Two Relief Valves	.09	(.2)	(2)	.000033
Check Valve	.045	(.1)	(1)	.000016
Pump	.59	(1.3)	(15)	.000245
Sublimator	1.59	(3.5)	(184)	.003
TCV	.14	(.3)	(6)	.000098
Elbow Wick Separator	.54	(1.2)	(30)	.00049
Expansion Tank	.36	(.8)	(85)	.00139
Package	1.41	(3.1)	(91)	.00148
Power Penalty			(37)	.0006
Delta P	.5	(1.1)		
Pump	.36	(.8)		
Total	10.9	(24.0)	(915)	.015

Vehicle Weight Penalty = 2 (System Weight - H_2O) + Power Penalty = (33.7 Pounds) 15.3 Kg



CONCEPT 17 - SUBLIMATOR, BUBBLE EXPANSION TANK, SINGLE STAGE ELBOW WICK SEPARATOR PLUS RESERVOIR STORAGE

CONCEPT #18

This concept consists of a simple bladder tank WMS, a three (3) fluid sublimator HRS, a single stage rotary separator condensate control system and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

During operation, water enters from the LCG and is circulated, by the pump, through the vehicle umbilical connector shutoff valve, the sublimator, the temperature control valve (TCV) and back to the LCG. The LCG water in the sublimator is the heat sink for the vent loop and is, in turn, cooled via heat transfer to the porous plate region of the sublimator. During umbilical operation, the umbilical connector shutoff valve is closed routing all water to a heat exchanger in the vehicle which replaces the porous plate heat sink. Thermal control is achieved by the TCV which varies the water flow to the LCG. LCG pressurization and makeup water is supplied via the check valve to the LCG.

The vent loop flow coming from the suit enters the sublimator where it is cooled below the dew point. The gas plus the condensed water enters the motor/rotary separator which separates the condensed water from the gas stream, and the gas is then returned to the suit via the fan. When passing through the fan, the gas is super heated above the dew point to prevent visor fogging. The separated water is delivered to the feed water circuit through a relief valve which prevents the introduction of gas to the feed water circuit.

For missions requiring EVA in the non-venting mode, the reservoir is not recharged to provide the volume for storage of the separated water.

Recharge of the system involves the following steps.

Open the dump valve.
Connect the fill connector and hold.
Disconnect the fill connector.
Close the dump valve.

If the motor/rotary separator relief valve were to fail open with the feed water lines dry and the shutoff valve open, the vent loop would exhaust to vacuum. The flow limiting orifice in the line to the sublimator was included to control gas leakage under these conditions.

A component weight and volume breakdown and vehicle weight penalty are as follows:

Component	System Weight Kg	(lbs)	System Volume (in^3)	m^3
H_2O Reservoir	.95	(2.1)	(382)	.00623
H_2O	3.13	(6.9)		--
Dump Valve	.09	(.2)	(6)	.000098
Fill Fitting	.045	(.1)	(3)	.00005
Shutoff Relief Valve	.09	(.2)	(6)	.000098
Check Valve	.045	(.1)	(1)	.000016
Pump	.59	(1.3)	(15)	.000245
Vehicle Connector	.23	(.5)	(6)	.000098
Relief Valve	.045	(.1)	(1)	.000016
Sublimator	1.59	(3.5)	(184)	.003
Motor/Rotary Separator	.54	(1.2)	(30)	.0005
TCV	.14	(.3)	(6)	.000098
Package	1.27	(2.8)	(68)	.0011
Power Penalty			(40)	.00065
Pump	.36	(.8)		
Rotary Separator	.18	(.4)		
Delta P	.36	(.8)		
Total	9.67	(21.3)	(748)	.012

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (30.8 Pounds) 14.0 Kg

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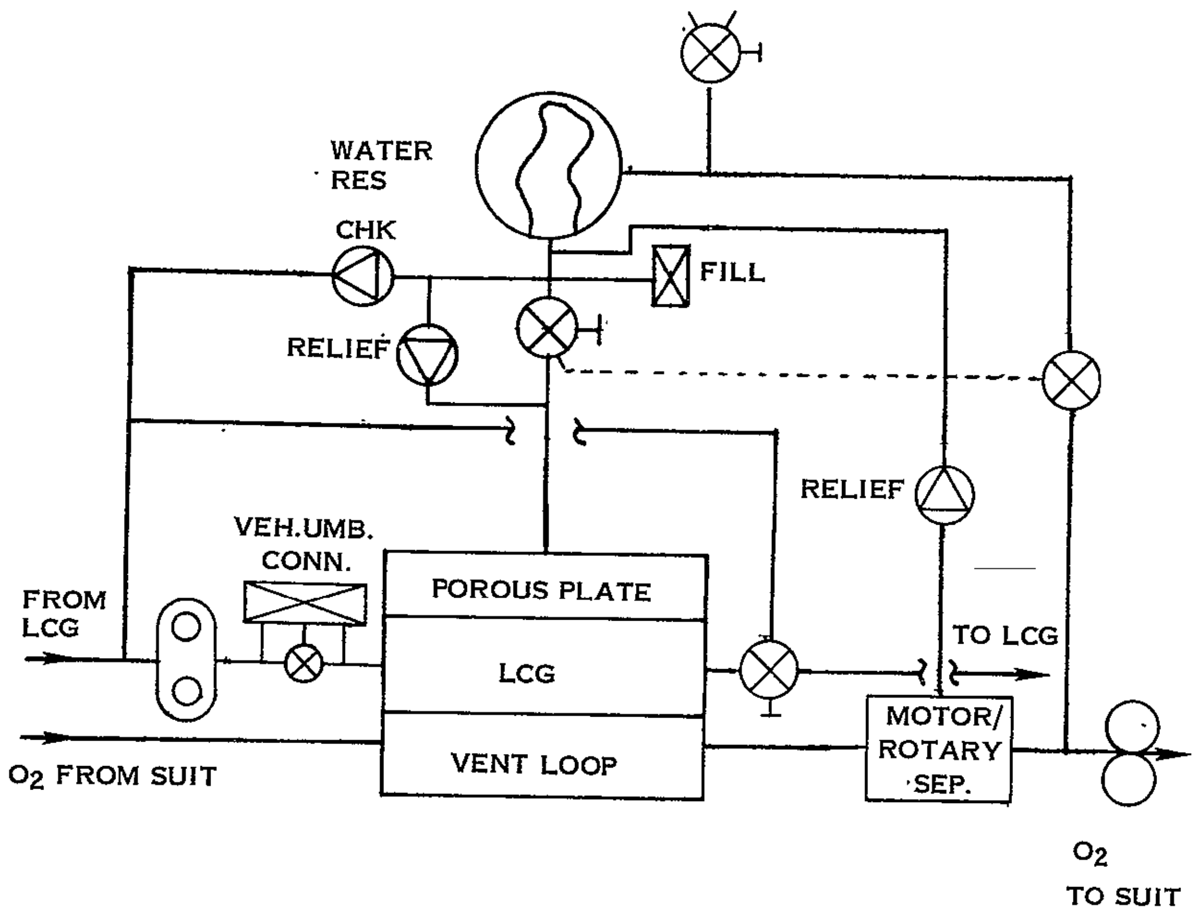


CONCEPT 18 — SUBLIMATOR, SIMPLE BLADDER TANK, SINGLE STAGE MOTOR/ROTARY SEPARATOR

CONCEPT #19

This concept consists of a simple bladder tank WMS, a three (3) fluid sublimator HRS, a single stage elbow wick separator for condensate control and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

This concept is similar to Concept #18, except that the motor/rotary separator is replaced by an elbow wick separator which is sized to contain the water separator during a four and one half hour EVA. Since the separated water is stored rather than utilized as feed water, the H_2O reservoir is larger than the tank in Concept #18.

Recharge of the system involves the following steps.

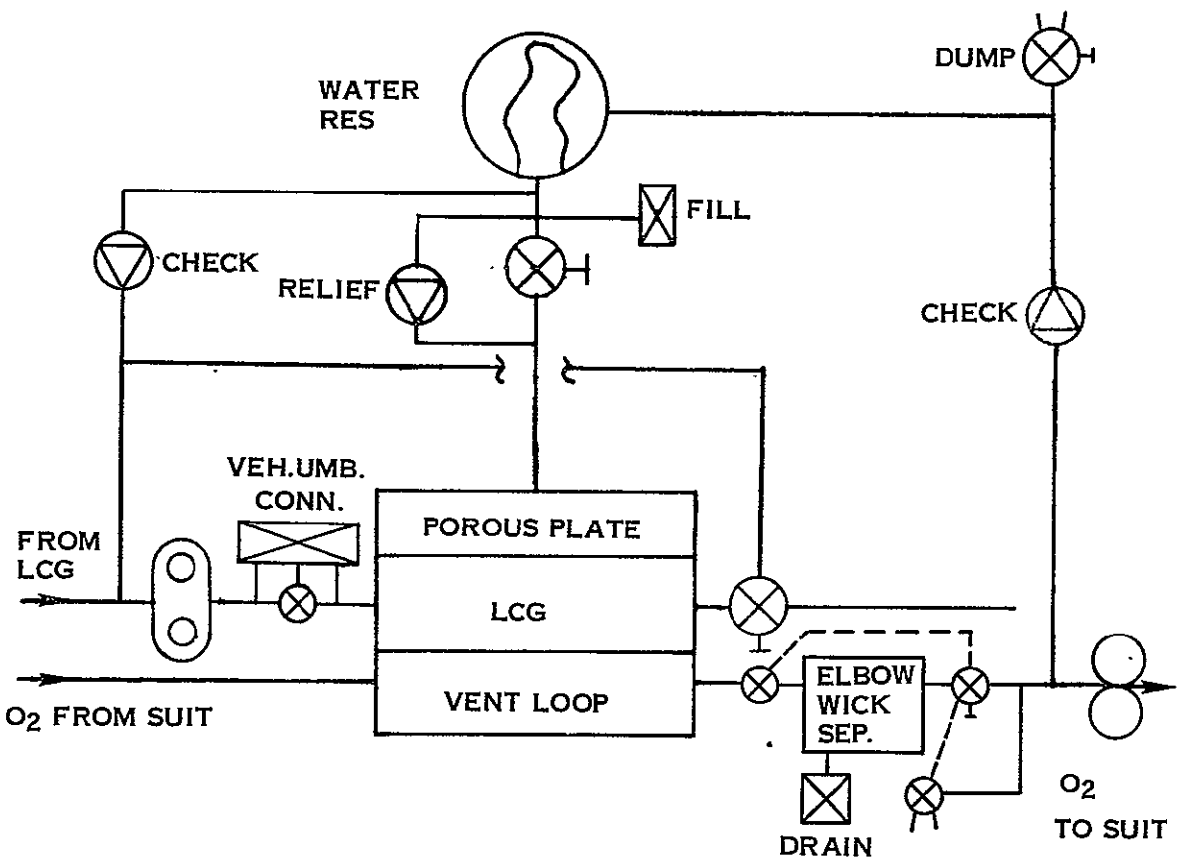
Close the three tier valve.
Connect a drain fitting.
Open the EVLSS O_2 supply valve and hold.
Close the O_2 supply valve.
Disconnect the three tier valve.
Open the dump valve
Connect the fill connector and hold.
Disconnect the fill connector.
Close the dump valve.

The backside of the bladder in the separator must be vented to vacuum during EVA; hence, failure of the bladder or the three tier valve could expose the vent loop to vacuum. An orifice is incorporated in the three tier valve exhaust to control leakage in the event of bladder or valve failure.

A component weight and volume breakdown and the vehicle weight penalty are as follows:

Component	System Weight Kg	(lbs)	System Volume (in^3)	m^3
H_2O Reservoir	1.04	(2.3)	(434)	.0071
H_2O	3.54	(7.8)		--
Dump Valve	.09	(.2)	(6)	.000098
Fill Fitting	.045	(.1)	(3)	.00005
Shutoff Relief Valve	.09	(.2)	(6)	.000098
Check Valve	.045	(.1)	(1)	.000016
Pump	.59	(1.3)	(15)	.000245
Vehicle Connector	.23	(.5)	(6)	.000098
Sublimator	1.59	(3.5)	(184)	.003
TCV	.14	(.3)	(6)	.000098
Elbow Wick Separator	1.19	(2.5)	(160)	.0026
3-In-1 Valve	.18	(.4)	(8)	.00013
Drain	.045	(.1)	(3)	.00005
Package	1.41	(3.1)	(80)	.0013
Power Penalty			(37)	.0006
Pump	.36	(.8)		
Delta P	.5	(1.1)		
Total	11.0	(24.3)	(949)	.015

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (34.9 Pounds) 15.8 Kg.



CONCEPT 19 — SUBLIMATOR, SIMPLE BLADDER TANK, SINGLE STAGE ELBOW WICK SEPARATOR

CONCEPT #20

This concept consists of a simple bladder tank WMS, a three (3) fluid sublimator, a single stage "Apollo" type elbow wick separator and a vehicle umbilical connector to permit up to 30 minutes of umbilical operation with the HRS shutdown. This concept is very nearly the same as the Apollo PLSS.

During operation, water enters from the LCG and is circulated, by the EVLSS pump, through the vehicle umbilical connector shutoff valve, the sublimator, the temperature control valve (TCV) and back to the LCG. The LCG water in the sublimator is the heat sink for the vent loop and is, in turn, cooled via heat transfer to the porous plate of the sublimator. During umbilical operation, the umbilical connector shutoff valve is closed routing all water to a heat exchanger in the vehicle which replaces the porous plate heat sink. Thermal comfort control is achieved by the TCV which varies the water flow to the LCG. LCG pressurization and makeup water is supplied via a ground charged accumulator which is referenced to suit pressure.

The vent loop flow coming from the suit enters the sublimator where it is cooled below the dew point condensing water. The gas plus the condensed water enters the elbow wick separator which separates the water from the gas stream, and the gas is then returned to the suit via the fan. When passing through the fan, the gas is super heated above the dew point to prevent visor fogging. The elbow wick separator is sized to contain the water condensed during one half hour of umbilical operation.

At the end of the half hour umbilical operation, the HRS is activated drawing water from the reservoir. The pressure differential between the separator and the collapsing bladder forces the separated water to the back side of the bladder.

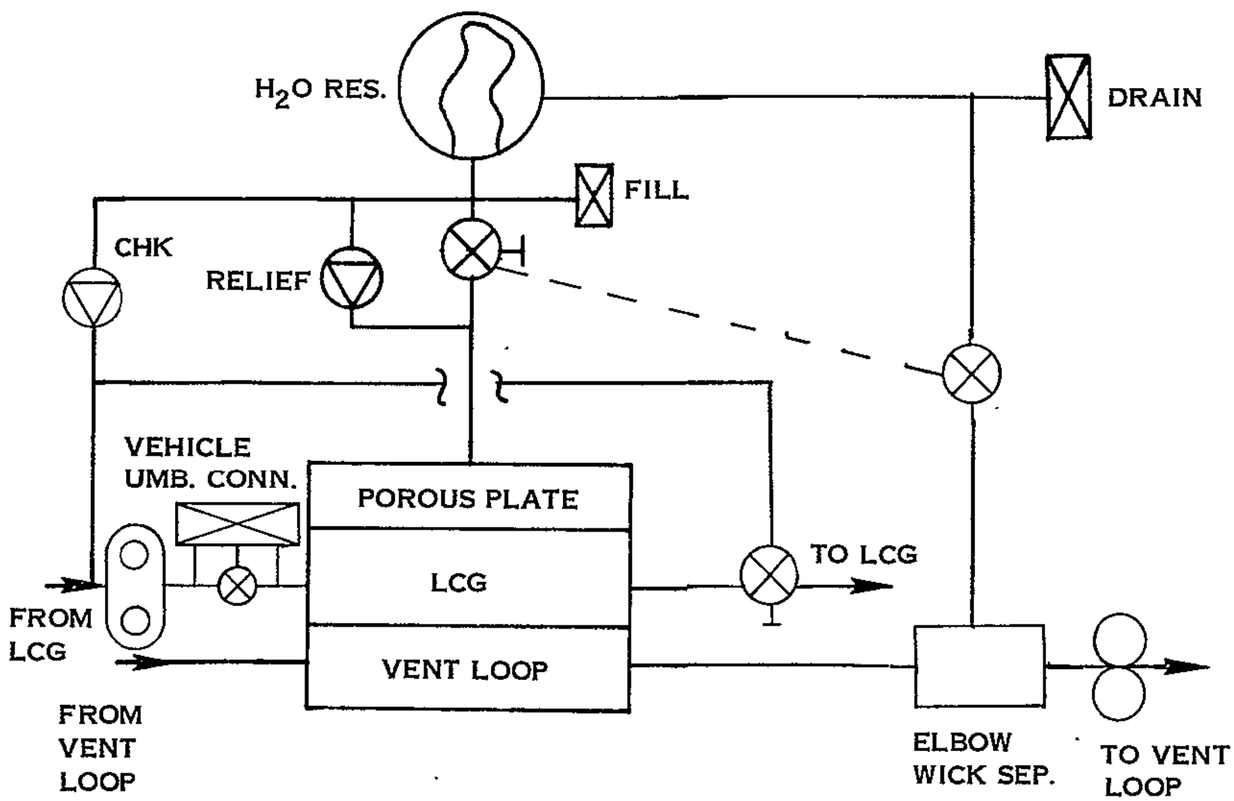
Recharge of the system involves the following steps:

Connect drain fitting.
Connect fill fitting and hold.
Disconnect the drain fitting.
Disconnect the fill fitting.

A component weight and volume breakdown and the vehicle weight penalty are as follows:

Component	System Weight Kg	(lbs)	System Volume (in^3)	m^3
H_2O Reservoir	1.04	(2.3)	(434)	.0071
H_2O	3.54	(7.8)	--	
Fill Fitting	.045	(.1)	(3)	.00005
Shutoff and Relief Valve	.09	(.2)	(6)	.000098
Check Valve	.045	(.1)	(1)	.000016
Pump	.59	(1.3)	(15)	.000245
Sublimator	.59	(3.5)	(184)	.003
TCV	.14	(.3)	(6)	.000098
Elbow Wick Separator	.54	(1.2)	(30)	.00049
Drain Fitting	.045	(.1)	(3)	.00005
Vehicle Umbilical Connector	.23	(.5)	(6)	.000098
Package	1.27	(2.8)	(72)	.00117
Power Penalty			(37)	.0006
Pump	.36	(.8)		
Delta P	.50	(1.1)		
Total	10.0	(22.1)	(797)	.013

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (30.5 Pounds) 13.9 Kg



CONCEPT 20. SUBLIMATOR., SIMPLE BLADDER TANK, ELBOW WICK SEPARATOR WITH RESERVOIR STORAGE

CONCEPT #21

This concept consists of a simple bladder tank WMS, a three (3) sublimator HRS, a first stage elbow scupper/second stage fan separator condensate control system and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

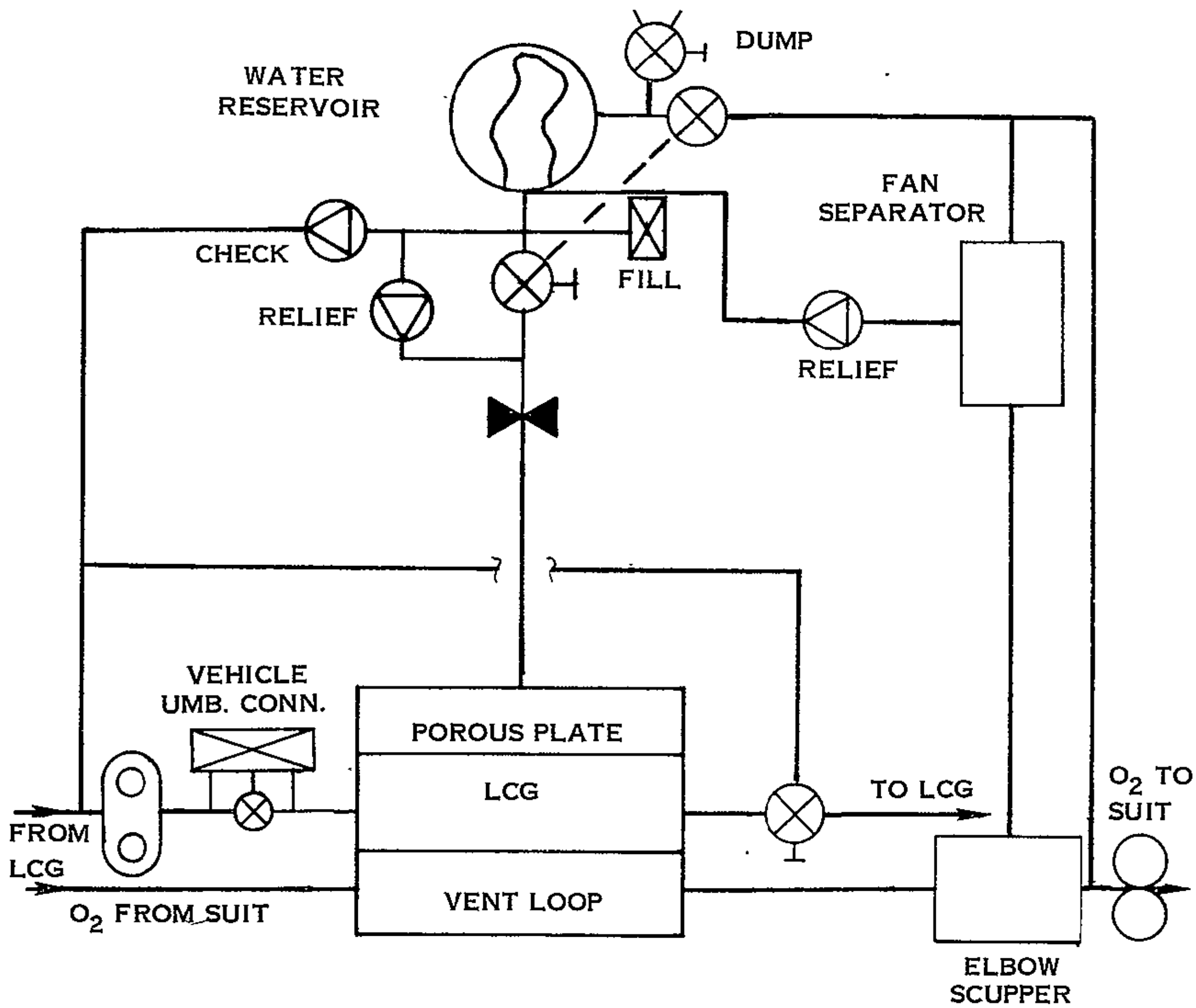
Operationally, this concept is similar to Concept #18. However, humidity control is accomplished in two stages. The elbow scupper removes all of the condensate from the main gas stream and a small amount of gas. The fan separator pumps the condensate to the water management system and provides the necessary head to force flow through the secondary loop.

Recharge is accomplished by utilizing the steps outlined for Concept #18.

A component weight and volume breakdown and the vehicle weight penalty are as follows:

Component	System Weight Kg (lbs)	System Volume (in^3) m^3
H_2O Reservoir	.95 (2.1)	(382) .0062
H_2O	3.13 (6.9)	--
Dump Valve	.09 (.2)	(6) .000098
Fill Fitting	.045 (.1)	(3) .00005
Shutoff Relief Valve	.09 (.2)	(6) .000098
Check Valve	.045 (.1)	(1) .000016
Pump	.59 (1.3)	(15) .000245
Vehicle Connector	.045 (.1)	(6) .000098
Sublimator	1.59 (3.5)	(184) .003
TCV	.14 (.3)	(6) .000098
Elbow Scupper	.14 (.3)	(8) .00013
Fan Separator	.50 (1.1)	(30) .0005
Relief Valve	.045 (.1)	(1) .000016
Package	1.32 (2.9)	(69) .0011
Power Penalty		(40) .00065
Pump	.36 (.8)	
Delta P	.36 (.8)	
Fan Separator	.36 (.8)	
Total	9.80 (21.6)	(757) .012

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (31.8 Pounds) 14.4 Kg



CONCEPT 21 - SUBLIMATOR, SIMPLE BLADDER TANK, 1ST STAGE SCUPPER 2ND STAGE FAN SEPARATOR

CONCEPT #22

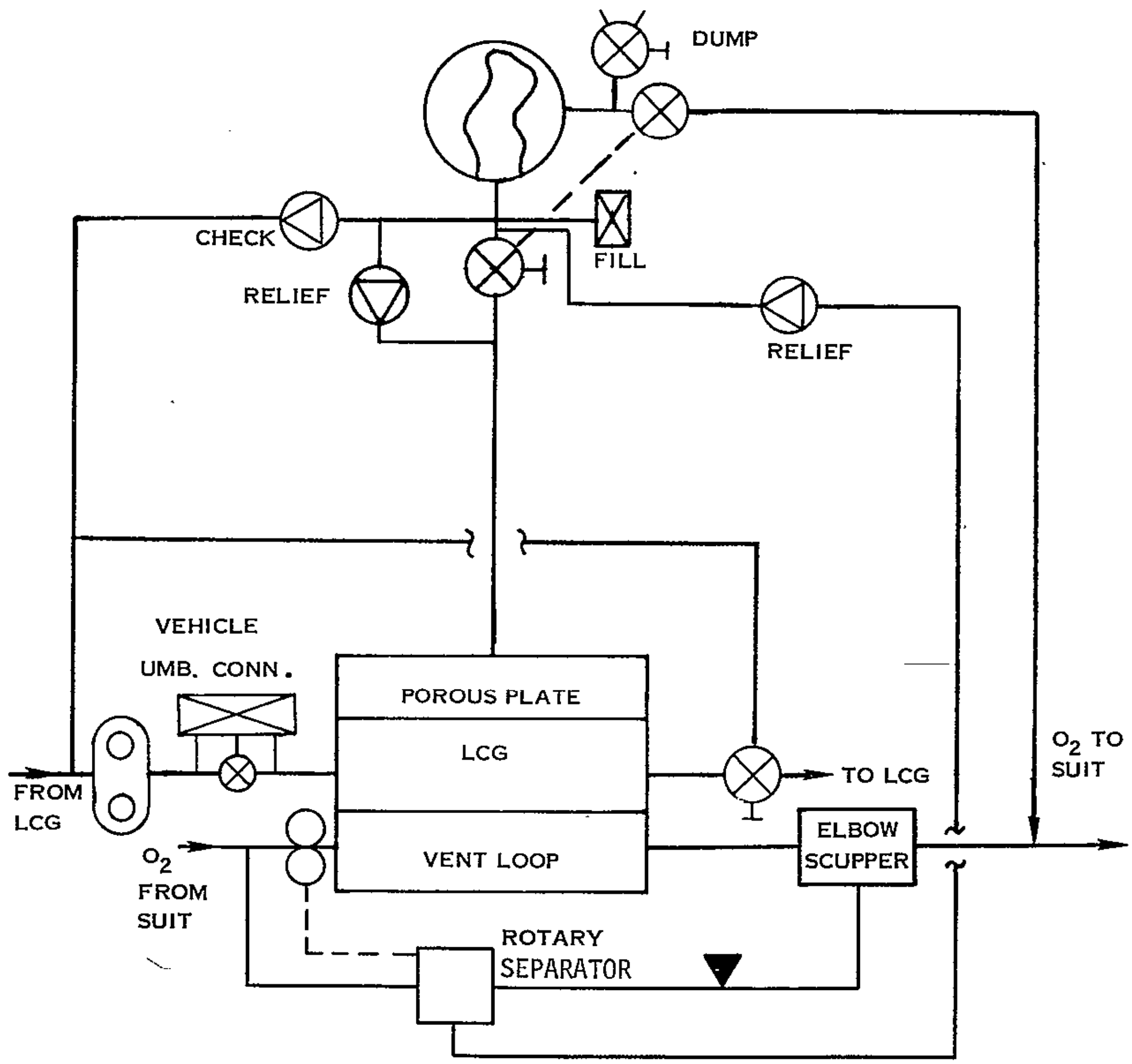
This concept consists of a simple bladder tank WMS, a three (3) fluid sublimator HRS, a first stage elbow scupper/second stage rotary separator condensate control system and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

This concept is similar to Concept #21, except that the fan separator is replaced by a rotary separator for condensate transfer to the WMS. Recharge is accomplished by utilizing the steps outlined for Concept #18.

A component weight and volume breakdown and the vehicle weight penalty for this concept are as follows:

Component	System Weight Kg	(lbs)	System Volume (in^3)	m^3
H_2O Reservoir	.95	(2.1)	(382)	.0062
H_2O	3.13	(6.9)		--
Dump Valve	.09	(.2)	(6)	.000098
Fill Fitting	.045	(.1)	(3)	.00005
Shutoff Relief Valve	.09	(.2)	(6)	.000098
Check Valve	.045	(.1)	(1)	.000016
Pump	.59	(1.3)	(15)	.000245
Vehicle Connector	.23	(.5)	(6)	.000098
Sublimator	1.59	(3.5)	(184)	.003
TCV	.14	(.3)	(6)	.000098
Elbow Scupper	.14	(.3)	(8)	.00013
Rotary Separator	.09	(.2)	(5)	.000082
Relief Valve	.045	(.1)	(1)	.000016
Package	1.27	(2.8)	(68)	.0011
Power Penalty			(42)	.00068
Pump	.36	(.8)		
Delta P	.41	(.9)		
Motor/Rotary Sep.	.18	(.4)		
Total	9.4	(20.7)	(747)	.012

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (29.7 Pounds) 13.5 Kg



CONCEPT 22 - SUBLIMATOR, SIMPLE BLADDER TANK, 1ST STAGE SCUPPER 2ND STAGE MOTOR/ROTARY SEPARATOR

CONCEPT #23

This concept consists of a simple bladder tank WMS, a three (3) fluid sublimator HRS, a first stage scupper/second stage elbow wick separator for condensate control and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

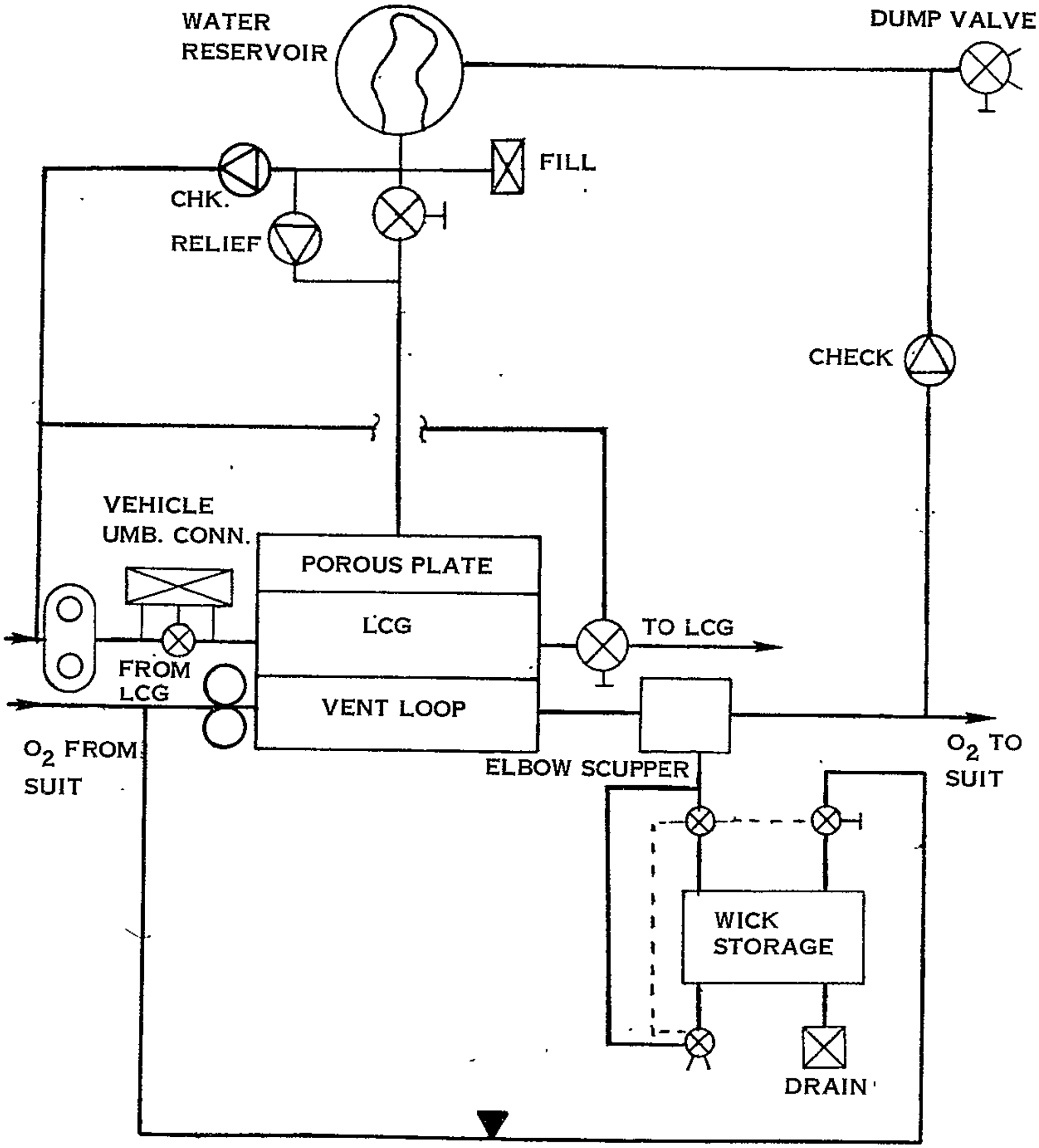
Operationally, this concept is similar to Concept #19, except humidity control is accomplished in two stages.

Recharge is accomplished by utilization of the steps outlined for Concept #19.

A component weight and volume breakdown and the vehicle weight penalty for this concept are as follows:

Component	System Weight Kg (lbs)	System Volume (in^3) m^3
H_2O Reservoir	1.04 (2.3)	(434) .0071
H_2O	3.54 (7.8)	--
Dump Valve	.09 (.2)	(6) .000098
Fill Fitting	.045 (.1)	(3) .00005
Shutoff and Relief Valve	.09 (.2)	(6) .000098
Check Valve	.045 (.1)	(1) .000016
Pump	.59 (1.3)	(15) .000245
Vehicle Connector	.23 (.5)	(6) .000098
Sublimator	1.59 (3.5)	(184) .003
TCV	.14 (.3)	(6) .000098
Elbow Scupper	.14 (.3)	(8) .00013
Wick Storage Separator	1.14 (2.5)	(160) .0026
Drain Fitting	.045 (.1)	(3) .00005
3-In-1 Valve	.18 (.4)	(8) .00013
Package	1.41 (3.1)	(89) .00145
Power Penalty		(34) .00055
Pump	.36 (.8)	
Delta P	.41 (.9)	
Total	11.1 (24.9)	(963) .015

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (34.9 Pounds) 15.8 Kg



CONCEPT 23. SUBLIMATOR, SIMPLE BLADDER TANK, 1ST STAGE SCUPPER 2ND STAGE ELBOW WICK STORAGE

CONCEPT #24

This concept consists of a simple bladder tank WMS, a three (3) fluid sublimator HRS, a first stage slurper/second stage motor rotary separator for condensate control and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

During operation, water enters from the LCG and is circulated, by the EVLSS pump, through the vehicle umbilical connector shut off valve, the sublimator, the temperature control valve (TCV) and back to the LCG. The LCG water in the sublimator is the heat sink for the vent loop and is in turn cooled via heat transfer to the porous plate of the sublimator. During umbilical operation, the umbilical connector shut off valve is closed routing all water to a heat exchanger in the vehicle which replaces the porous plate HRS heat sink. Thermal comfort control is achieved by the TCV which varies the water flow to the LCG. LCG pressurization and make up water is supplied via the check valve between the feed water circuit and the LCG.

The vent loop flow coming from the suit is circulated by the fan through the LiOH canister and the vent loop portion of the sublimator/slurper.

Water separation is accomplished in two stages. Approximately three (3) percent of the main stream flow is directed through the slurper to the upstream side of the fan. The pressure differential between these two points continually drains the condensed water from the heat exchanger. The water/gas mixture enters the rotary separator; it separates the water from the gas stream and returns the gas to the vent loop. Separated water is directed to the feed water circuit through a relief valve which prevents the introduction of gas to the feed-water circuit. The rotary separator is directly driven by the ventilation loop fan.

An accumulator is located between the rotary separator and the charged water reservoir to collect water separated during one half hour of pre EVA umbilical operation. The accumulator is pressure referenced to the high pressure side of the fan while the water reservoir is referenced to the low pressure side of the fan. Because of this pressure differential, the water in the accumulator is used first leaving the accumulator dry at start up of subsequent EVA's.

For missions requiring EVA in the non-venting mode, the reservoir is not recharged to provide the volume for storage of the separator water.

Recharge of the system involves the following steps.

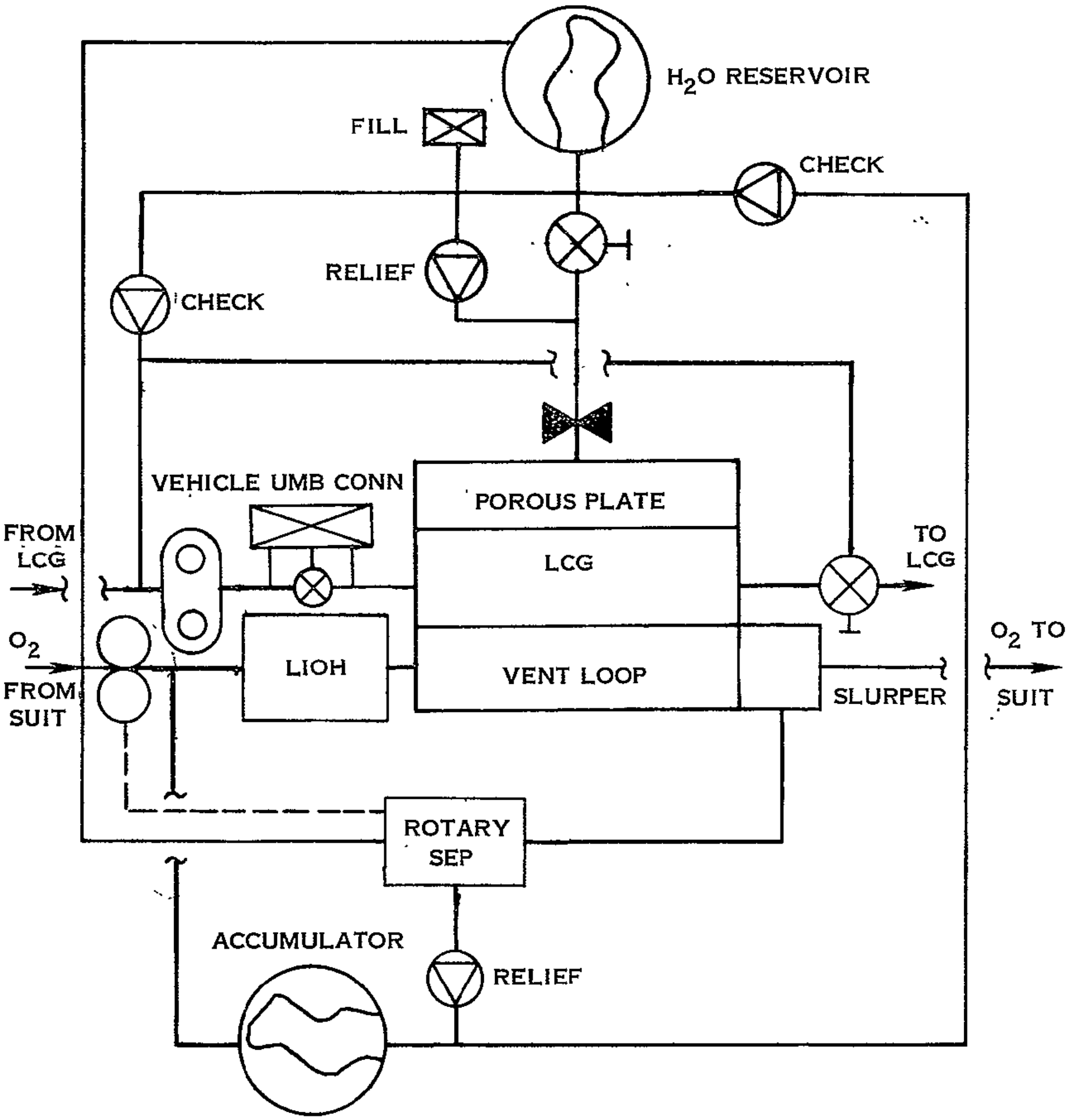
Connect the fill connector and hold.
Disconnect the fill connector.

If the motor/rotary separator relief valve were to fail open with the feed water lines dry and the shut off valve open, the vent loop would exhaust to vacuum. The flow limiting orifice in the line to the sublimator was included to control gas leakage under these conditions.

A component weight and volume breakdown and the vehicle weight penalty for this concept are as follows:

Component	System Weight Kg	(lbs)	System Volume (in³)	m³
H_2O Reservoir	.95	(2.1)	(382)	.00623
H_2O	3.13	(6.9)		--
Orifice	.045	(.1)	(6)	.000098
Fill Fitting	.045	(.1)	(3)	.00005
Shutoff & Relief	.09	(.2)	(6)	.000098
Two Check Valves	.09	(.2)	(2)	.000033
Pump	.59	(1.3)	(15)	.000245
Vehicle Conn.	.23	(.5)	(6)	.000098
Sublimator	1.59	(3.5)	(184)	.003
Slurper	.14	(.3)	(10)	.000163
Rotary Separator	.09	(.2)	(5)	.000083
Relief Valve	.045	(.1)	(1)	.000016
TCV	.14	(.3)	(6)	.000098
Accumulator	.14	(.3)	(12)	.0002
Package	1.27	(2.8)	(68)	.0011
Power Penalty			(29)	.00047
Pump	.36	(.8)		
Motor/Rotary Separator	.18	(.4)		
ΔP	.09	(.2)		
Total	9.22	(20.3)	(730)	.012

Vehicle Weight = 2 (System Weight - H_2O) + Vehicle Power Penalty
= (28.2 Pounds) 12.8 Kg



CONCEPT 24 - SUBLIMATOR, SIMPLE BLADDER TANK, 1ST STAGE SLURPER 2ND STAGE ROTARY SEPARATOR

CONCEPT #25

This concept consists of a simple bladder tank WMS, a three (3) fluid sublimator HRS, a first stage slurper/second stage elbow wick separator condensate control system and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

This concept is similar to concept 24 except that the motor/rotary separator is replaced by an elbow wick separator which is sized to contain the water separated during a four and one half hour EVA. Since the separated water is stored rather than utilized as feed water, the H_2O reservoir is larger than the tank in concept 24.

Recharge of the system involves the following steps:

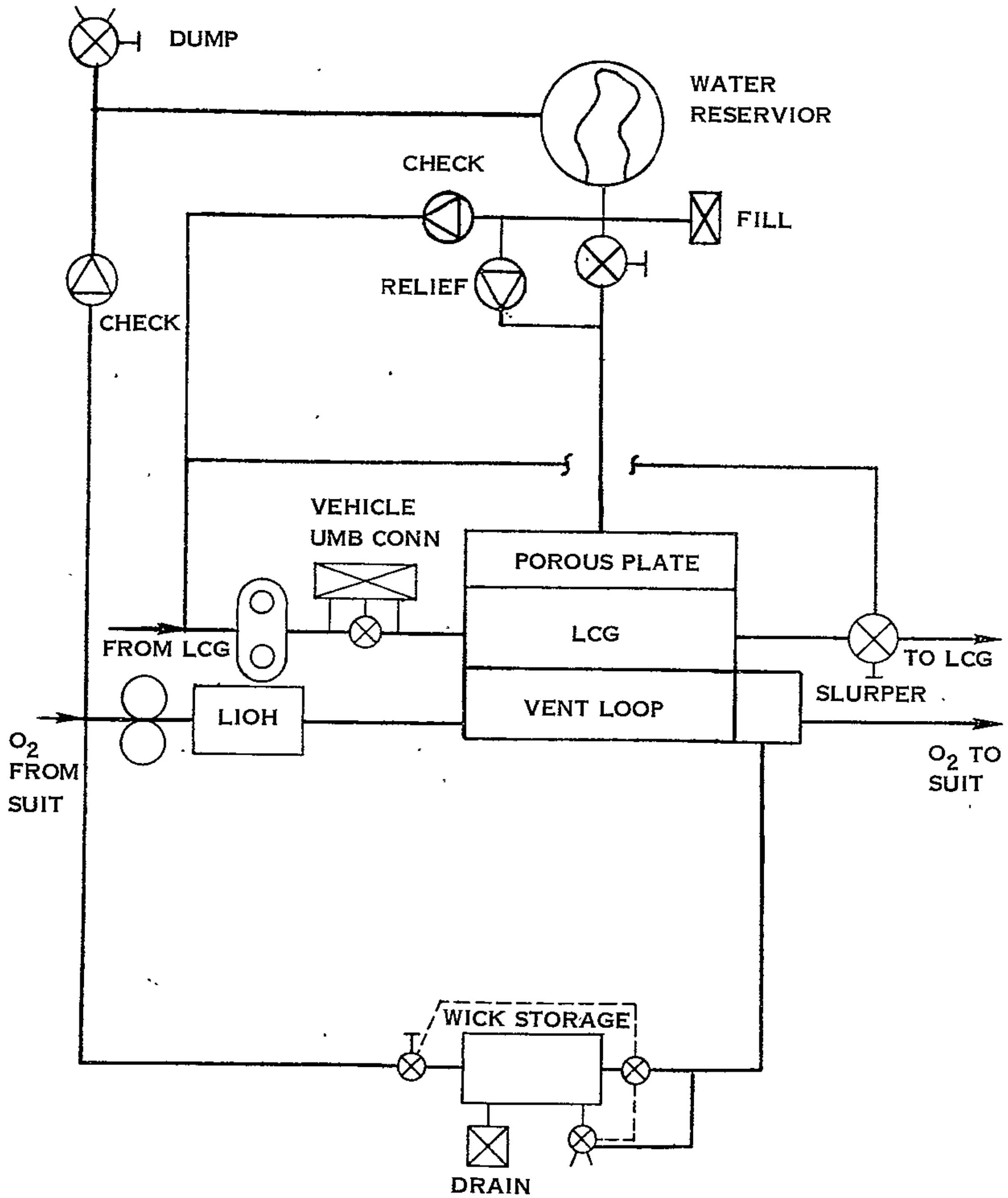
Close the three tier valve
Connect drain fitting
Open EVLSS O_2 supply valve and hold
Close the O_2 valve
Disconnect drain fitting
Open three tier valve
Connect fill line and hold
Open dump valve
Disconnect fill line
Close dump valve

The backside of the bladder in the separator must be vented to vacuum during EVA; hence, failure of the bladder or the three tier valve could expose the vent loop to vacuum. An orifice is incorporated in the three tier valve exhaust to control leakage in the event of bladder or valve failure.

Component	System Weight Kg (lbs)	System Volume (in^3) m^3
H_2O Reservoir	1.04 (2.3)	(434) .0071
H_2O	3.54 (7.8)	--
Dump Valve	.09 (.2)	(6) .000098
Fill Conn.	.045 (.1)	(3) .00005
Shutoff Valve	.09 (.2)	(6) .000098
Check Valve	.045 (.1)	(1) .000016
Pump	.59 (1.3)	(15) .000245
Vehicle Conn.	.23 (.5)	(6) .000098
Sublimator	1.59 (3.5)	(184) .003
Slurper	.14 (.3)	(10) .000163
TCV	.14 (.3)	(6) .000098
Elbow Wick Separator	1.14 (2.5)	(160) .0026
Drain Conn.	.045 (.1)	(3) .00005

Component	System Weight Kg	(lbs)	System Volume (in^3)	m^3
3-in-1 Valve	.18	(.4)	(8)	.00013
Package	1.36	(3.0)		--
Power Penalty			(81)	.0013
Pump	.36	(.8)	(21)	.00034
Δ P	.09	(.2)		--
Total	10.7	(23.6)	(949)	.015

The Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (32.6 pounds) 14.8 Kg



CONCEPT 25 - SUBLIMATOR, SIMPLE BLADDER TANK, 1ST STAGE SLURPER, 2ND STAGE WICK STORAGE

CONCEPT #26

This concept consists of a simple bladder tank plus pump WMS, a two two fluid flash evaporator HRS, a single stage motor/rotary separator and a vehicle umbilical connector for up to 4.5 hours of umbilical operation with the HRS shutdown.

During operation, water enters from the LCG and is circulated, by the pump, through the vehicle umbilical connector shut off valve, the flash evaporator, the vent loop to LCG Hx., the thermal control valve (TCS), and back to the LCG. The LCG water is cooled in the flash evaporator and in turn the LCG water cools the vent loop O_2 via the vent loop to LCG Hx.

During umbilical operation, the umbilical connector shutoff valve is closed routing all water to a heat exchanger in the vehicle which replaces the flash evaporator heat sink. Thermal comfort control is achieved by the TCV which varies the water flow to the LCG. LCG pressurization and make up water is supplied via a ground charged accumulator which is referenced to suit pressure.

The vent loop flow coming from the suit enters the heat exchanger where it is cooled below the dew point. The gas plus the condensed water enters the motor/rotary separator which separates the water from the gas stream and the gas is then returned to the sink via the fan. When passing through the fan, the gas is superheated above the dew point to prevent visor fogging. The separated water is delivered to the feed water circuit through a relief valve which prevents the introduction of gas to the feed water circuit.

For missions requiring EVA in the non-venting mode the reservoir is not recharged to provide the volume for storage of the separated water.

The pump in the feed water circuit provides water to the flash evaporator nozzle at the required operating pressure.

Recharge of the system involves the following steps:

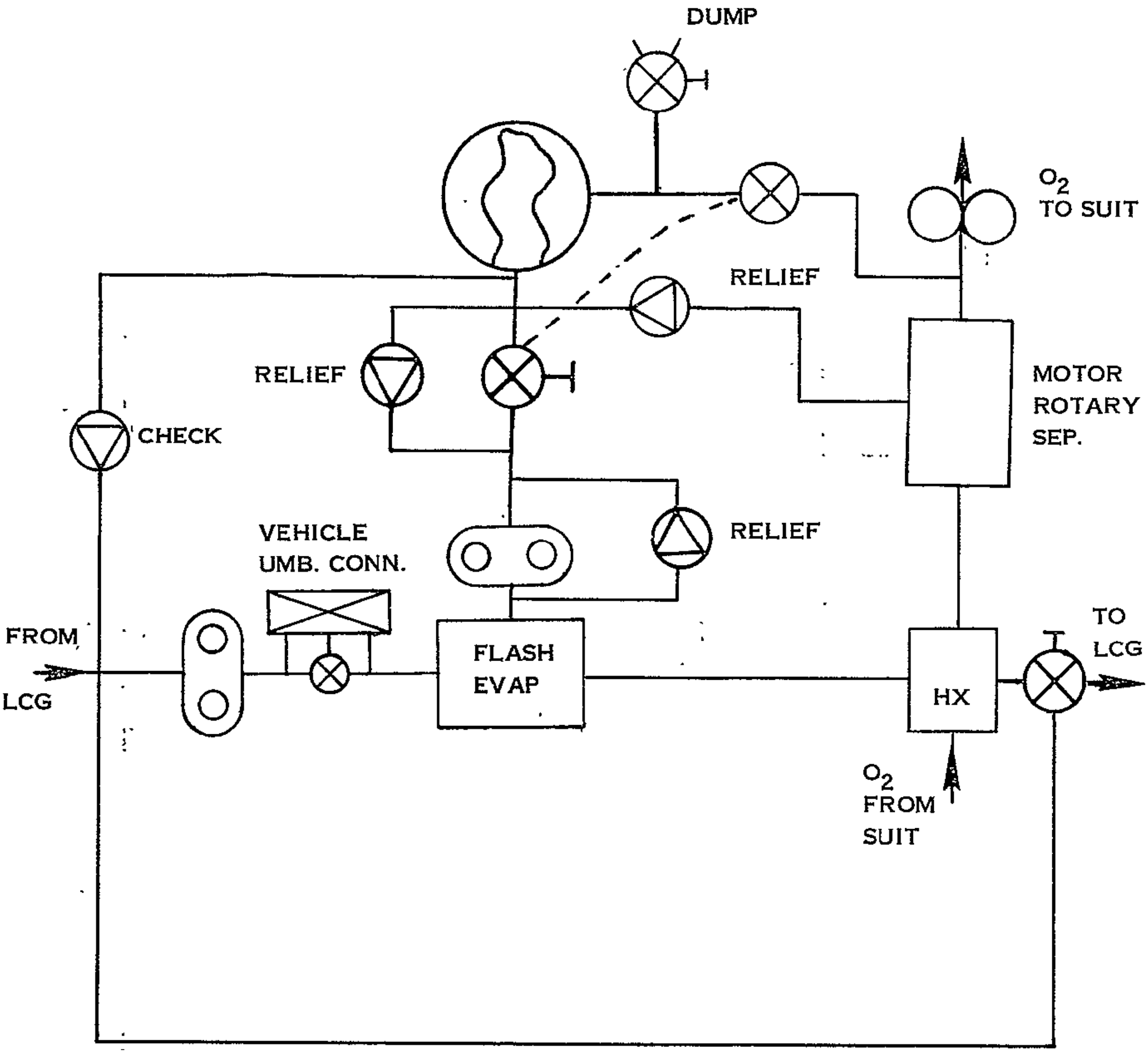
Open the dump valve
Connect the fill connector - hold for 10 minutes
Disconnect the fill connector
Close the dump valve

If the motor/rotary separator relief valve were to fail open with the feed water lines dry and the shutoff valve open, the vent loop would exhaust to vacuum. The flow limiting orifice in the line to the sublimator was included to control gas leakage under these conditions.

A component weight and volume breakdown and the vehicle weight penalty for this concept are as follows:

Component	System Weight Kg (lbs)		System Volume (in^3) m^3	
Water Reservoir	1.04	(2.2)	(405)	.0066
H_2O	3.31	(7.3)		--
Dump Valve	.09	(.2)	(6)	.000098
Three Relief Valves	.14	(.3)	(3)	.00005
Shutoff Valves	.09	(.2)	(6)	.000098
Flash Evaporator Pump	.91	(2.0)	(15)	.000245
Pump	.59	(1.3)	(15)	.000245
Controller	.68	(1.5)	(40)	.000652
Flash Evaporator	1.09	(2.4)	(196)	.0032
Fill Fitting	.045	(.1)	(3)	.00005
Vehicle Conn.	.23	(.5)	(6)	.000098
Check Valve	.045	(.1)	(1)	.000016
Hx.	.36	(.8)	(10)	.000163
Motor/Rotary Separator	.54	(1.2)	(30)	.0005
TCV	.14	(.3)	(6)	.000098
Package	1.59	(3.5)	(81)	.00132
Power Penalty			(74)	.0012
Pump	.36	(.8)		
Motor/Rotary	.18	(.4)		
Flash Evaporator Pump	.72	(1.6)		
Flash Evaporator Controller	.18	(.4)		
ΔP	.41	(.9)		
Total	12.7	(28.0)	(894)	.015

The Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (45.0 pounds) 20.4 Kg



CONCEPT 26. FLASH EVAPORATOR, SIMPLE BLADDER TANK, SINGLE STAGE MOROR/ROTARY SEPARATOR

CONCEPT #27

This concept consists of a simple bladder tank plus a pump WMS, a two-two fluid flash evaporator HRS, a single stage elbow wick separator and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

This concept is similar to concept 26 except that the motor/rotary separator is replaced by an elbow wick separator which is sized to contain the water separated during a four and one half hour EVA. Since the separated water is stored rather than utilized as feed water, the H_2O reservoir is larger than the tank in Concept 26.

Recharge of the system involves the following steps.

Close the three tier valve
Connect drain fitting
Open the EVLSS O_2 supply valve and hold
Disconnect drain fitting
Open the three tier valve
Close the EVLSS O_2 supply valve
Open the dump valve
Connect fill fitting and hold
Disconnect fill fitting
Close dump valve

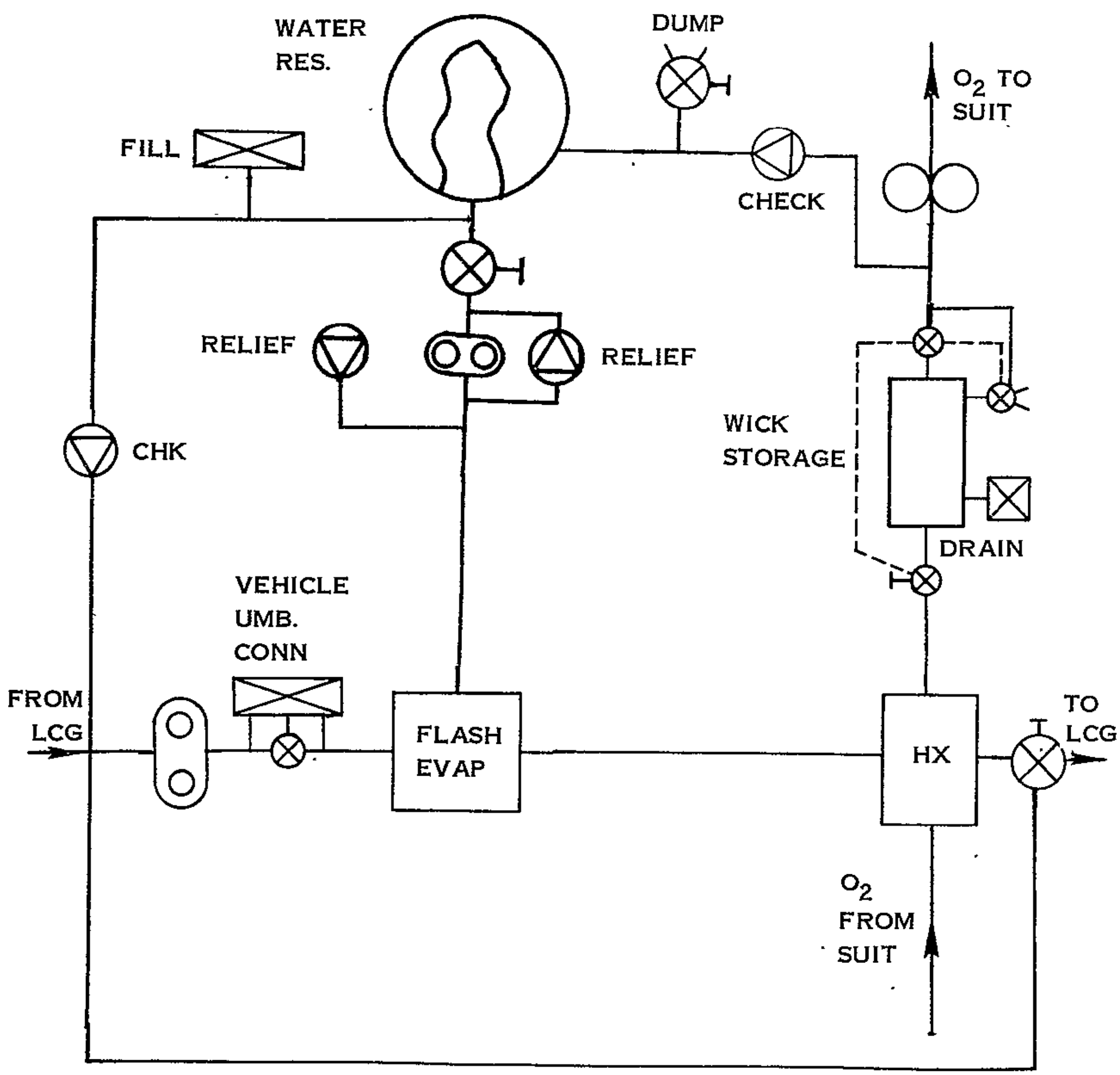
The backside of the bladder in the separator must be vented to vacuum during EVA failure of the bladder or the three tier valve could expose the vent loop to vacuum. An orifice is incorporated in the three tier valve exhaust to control leakage in the event of bladder or valve failure.

A component weight and volume breakdown and the vehicle weight penalty are as follows:

Component	System Weight Kg (lbs)	System Volume (in^3) m^3
Water Reservoir	1.09 (2.4)	(457) .00745
H_2O	3.77 (8.3)	--
Dump Valve	.09 (.2)	(6) .000098
3 Relief Valves	.14 (.3)	(3) .00005
Shutoff Valve	.09 (.2)	(6) .000098
Flash Evaporator Pump	.91 (2.0)	(15) .000245
Controller	.68 (1.5)	(30) .0005
Pump	.59 (1.3)	(15) .000245
Flash Evaporator	1.09 (2.4)	(196) .0032
Vehicle Conn.	.23 (.5)	(6) .000098
Check Valve	.045 (.1)	(1) .000016
Hx	.36 (.8)	(10) .000163

Component	System Weight Kg (lbs)		System Volume (in^3) m^3	
Elbow Wick Separator	1.14	(2.5)	(160)	.0026
Drain Connector	.045	(.1)	(3)	.00005
3-inl Valve	.18	(.4)	(8)	.00013
Fill Fitting	.14	(.3)	(36)	.00059
TCV	.14	(.3)	(6)	.000098
Package	1.82	(4.0)	(94)	.0015
Power Penalty				
Pump	.36	(..8)		
Flash Evaporator Pump	.73	(1.6)		
Flash Evaporator Contr.	.18	(.4)	(77)	.00126
Δ P	.50	(1.1)		
Total	14.3	(31.5)	(1125)	.018

The Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (50.1 pounds) 22.7 Kg



CONCEPT 27. FLASH EVAPORATOR, SIMPLE BLADDER TANK, SINGLE STAGE ELBOW WICK SEPARATOR

CONCEPT #28

This concept consists of a simple bladder tank plus pump WMS, a two-two fluid flash evaporator HRS, an "Apollo" type elbow wick condensate control system and a vehicle umbilical connector to permit up to 30 minutes of umbilical operation with the HRS shutdown.

During operation, water enters from the LCG and is circulated, by the pump, through the vehicle umbilical connector shutoff valve, the flash evaporator, the vent loop to LCG Hx, the temperature control valve (TCV) and back to the LCG. The LCG water is cooled in the flash evaporator and in turn the LCG water cools the vent loop O_2 via the vent loop to LCG Hx.

During umbilical operation, the umbilical connector shutoff valve is closed routing all water to a heat exchanger in the vehicle which replaces the flash evaporator heat sink. Thermal comfort control is achieved by the TCV which varies the water flow to the LCG. LCG pressurization and makeup water is supplied via a ground charged accumulator which is referenced to suit pressure.

The vent loop flow coming from the suit enters the heat exchanger where it is cooled below the dew point condensing water. The gas plus the condensed water enters the elbow wick separator which separates the condensed water from the gas stream and the gas stream is then returned to the suit via the fan. When passing through the fan, the gas is superheated above the dew point to prevent visor fogging. The elbow wick separator is sized to contain the water condensed during one half hour of umbilical operation. At the end of the half hour umbilical operation, the HRS is activated draining water from the reservoir. The pressure differential between the separator and the collapsing bladder forces the separated water to the back side of the bladder.

Recharge of the system involves the following steps:

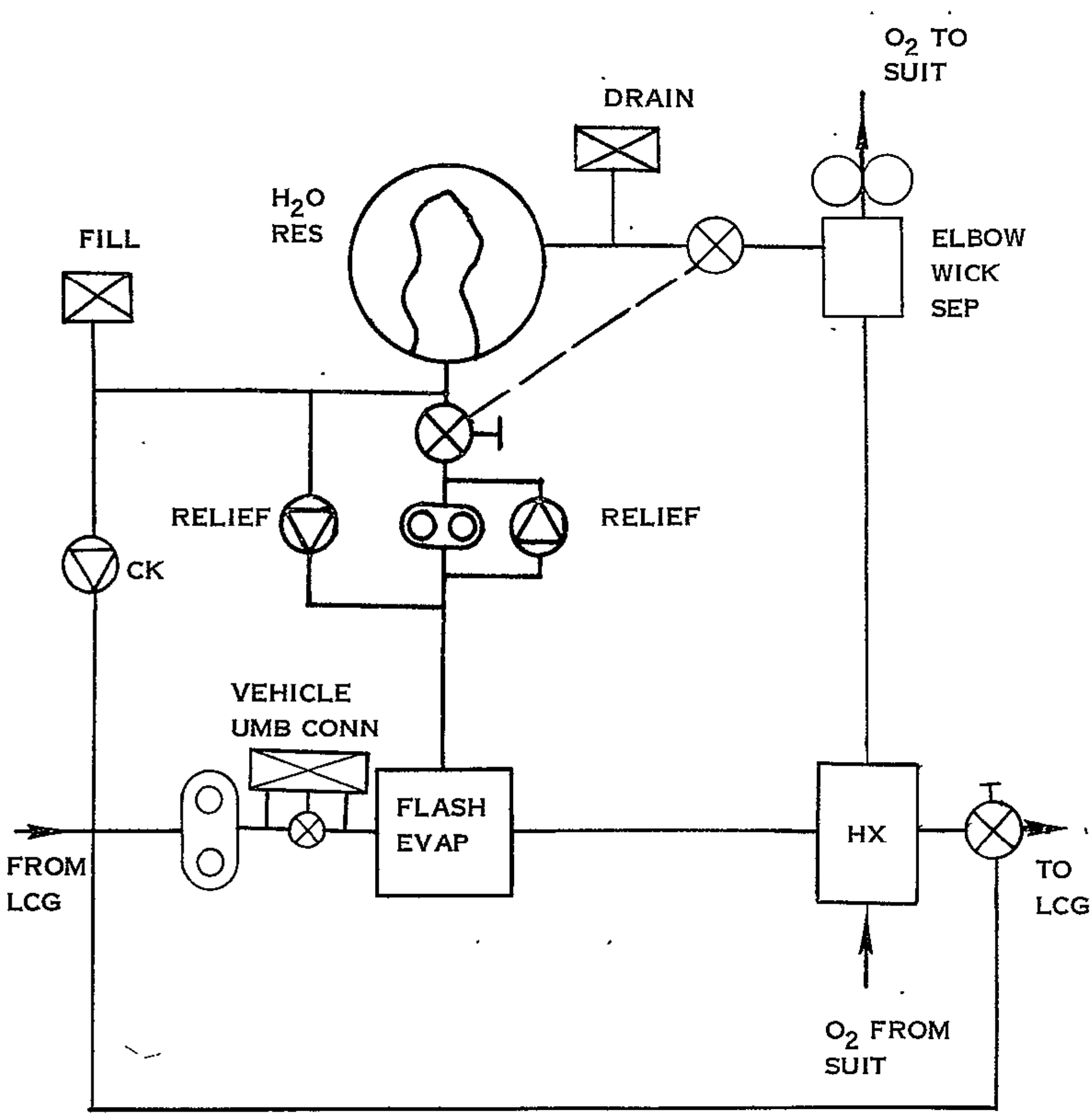
Connect drain fitting
Connect fill fitting and hold
Disconnect the drain fitting
Disconnect the fill fitting

The pump in the feed water line provides water to the flash evaporator at the required operating pressure.

A component weight and volume breakdown and the vehicle weight penalty of this concept are as follows:

Component	System Weight Kg (lbs)	System Volume (in^3) m^3
Water Reservoir	1.09 (2.4)	(457) .00745
H_2O	3.77 (8.3)	--
2 Relief Valves	.09 (.2)	(2) .000033
Shutoff Valve	.09 (.2)	(6) .000098
Flash Evaporator Pump	.91 (2.0)	(15) .000245
Controller	.68 (1.5)	(30) .00049
Pump	.59 (1.3)	(15) .000245
Flash Evaporator	1.09 (2.4)	(196) .0032
Check Valve	.045 (.1)	(1) .000016
Hx	.36 (.8)	(10) .000163
Elbow Wick Separator	.54 (1.2)	(30) .00049
Drain Connector	.045 (.1)	(3) .00005
Fill Fitting	.045 (.1)	(3) .00005
TCV	.14 (.3)	(6) .000098
Vehicle Umbilical Conn.	.23 (.5)	(6) .000098
Package	1.73 (3.8)	(84) .00137
Power Penalty		(77) .00126
Pump	.36 (.8)	
Flash Evaporator Pump	.73 (1.6)	
Flash Evaporator Controller	.18 (.4)	
ΔP	.15 (1.10)	
Total	13.2 (29.1)	(941) .015

The Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = 45.5 pounds) 20.7



CONCEPT 28 - FLASH EVAPORATOR, SIMPLE BLADDER TANK, ELBOW WICK SEPARATOR WITH RESERVOIR STORAGE

CONCEPT #29

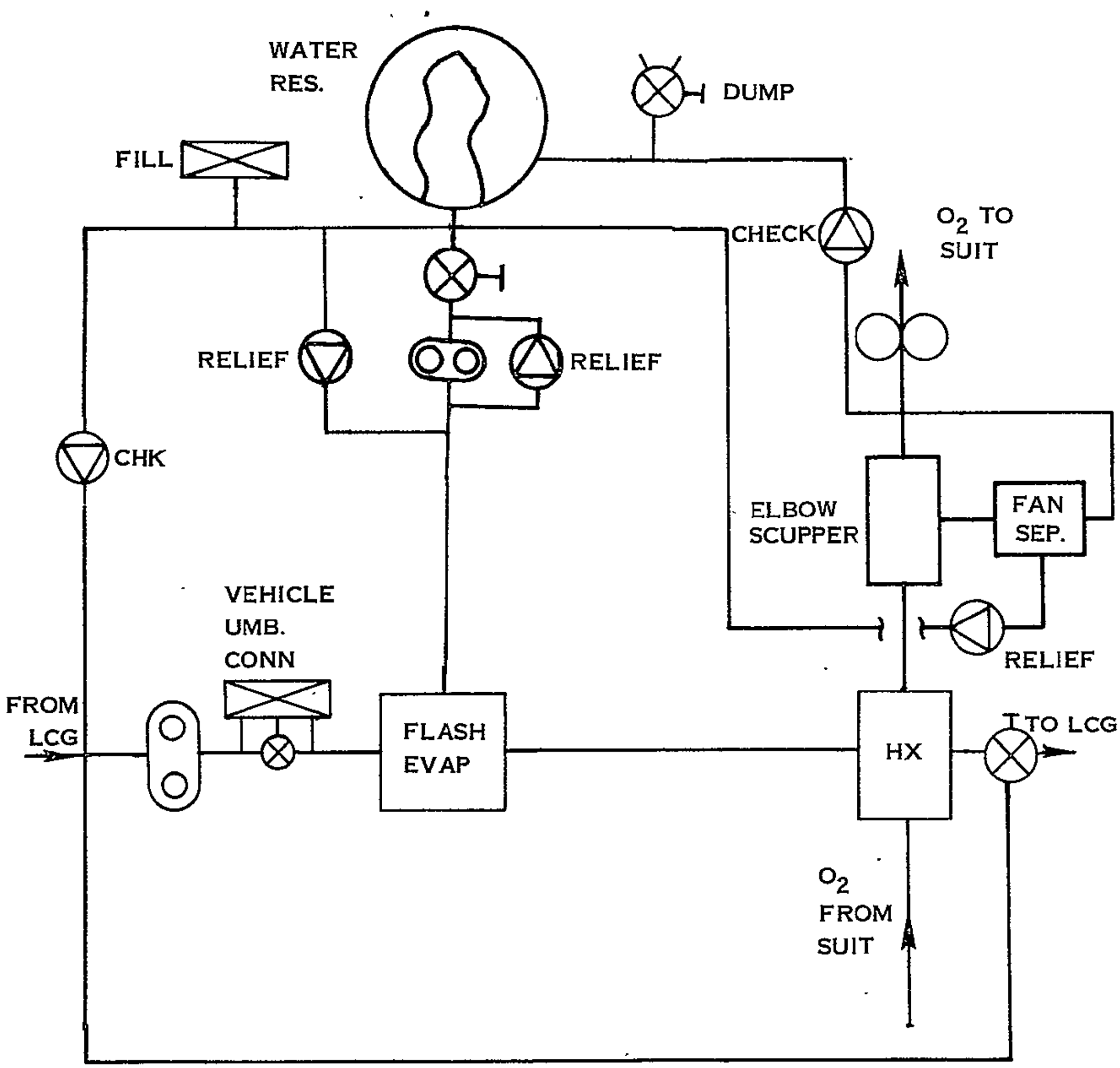
This concept consists of a simple bladder tank plus pump WMS, a two-two fluid flash evaporator HRS, a first stage elbow scupper/second stage fan separator condensate control system and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

Operationally, this concept performs in exactly the same way as Concept #26. However, the humidity control is accomplished in two stages. The elbow scupper removes all of the condensate from the main gas stream and with a small amount of gas. The fan separator pumps the condensate to the water management system and provides the necessary head to force flow through the secondary loop.

Recharge is accomplished utilizing the procedure outlines for Concept 26. A component weight and volume breakdown and the vehicle weight penalty of this concept are as follows:

Component	System Weight Kg	(lbs)	System Volume in³)	m³
Water Reservoir	1.0	(2.2)	(405)	.0066
H_2O	3.31	(7.3)	--	
Dump Valve	.14	(.3)	(6)	.000098
3 Relief Valves	.14	(.3)	(3)	.00005
Shutoff Valve	.09	(.2)	(6)	.000098
Flash Evaporator Pump	.91	(2.0)	(15)	.000245
Controller	.68	(1.5)	(40)	.00065
Pump	.59	(1.3)	(15)	.000245
Flash Evaporator	1.09	(2.4)	(196)	.0032
Vehicle Conn.	.23	(.5)	(6)	.000098
Check Valve	.045	(.1)	(1)	.000016
Hx	.310	(.8)	(10)	.000163
Fan Separator	.5	(1.1)	(30)	.0005
Elbow Scrupper	.14	(.3)	(8)	.00013
TCV	.14	(.3)	(6)	.000098
Package	1.68	(3.7)	(84)	.00137
Fill Fitting	.041	(.1)	(3)	.00005
Power Penalty			(88)	.00143
Pump	.36	(.8)		
Flash Evaporator Pump	.73	(1.6)		
Flash Evaporator Controller	.18	(.4)		
ΔP	.36	(.8)		
Fan Separator	.36	(.8)		
Total	13.10	(28.8)	(922)	.015

The Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = 46.8 pounds) 21.2 Kg



CONCEPT 29. FLASH EVAPORATOR, SIMPLE BLADDER TANK, 1ST STAGE SCUPPER 2ND STAGE FAN SEPARATOR

CONCEPT #30

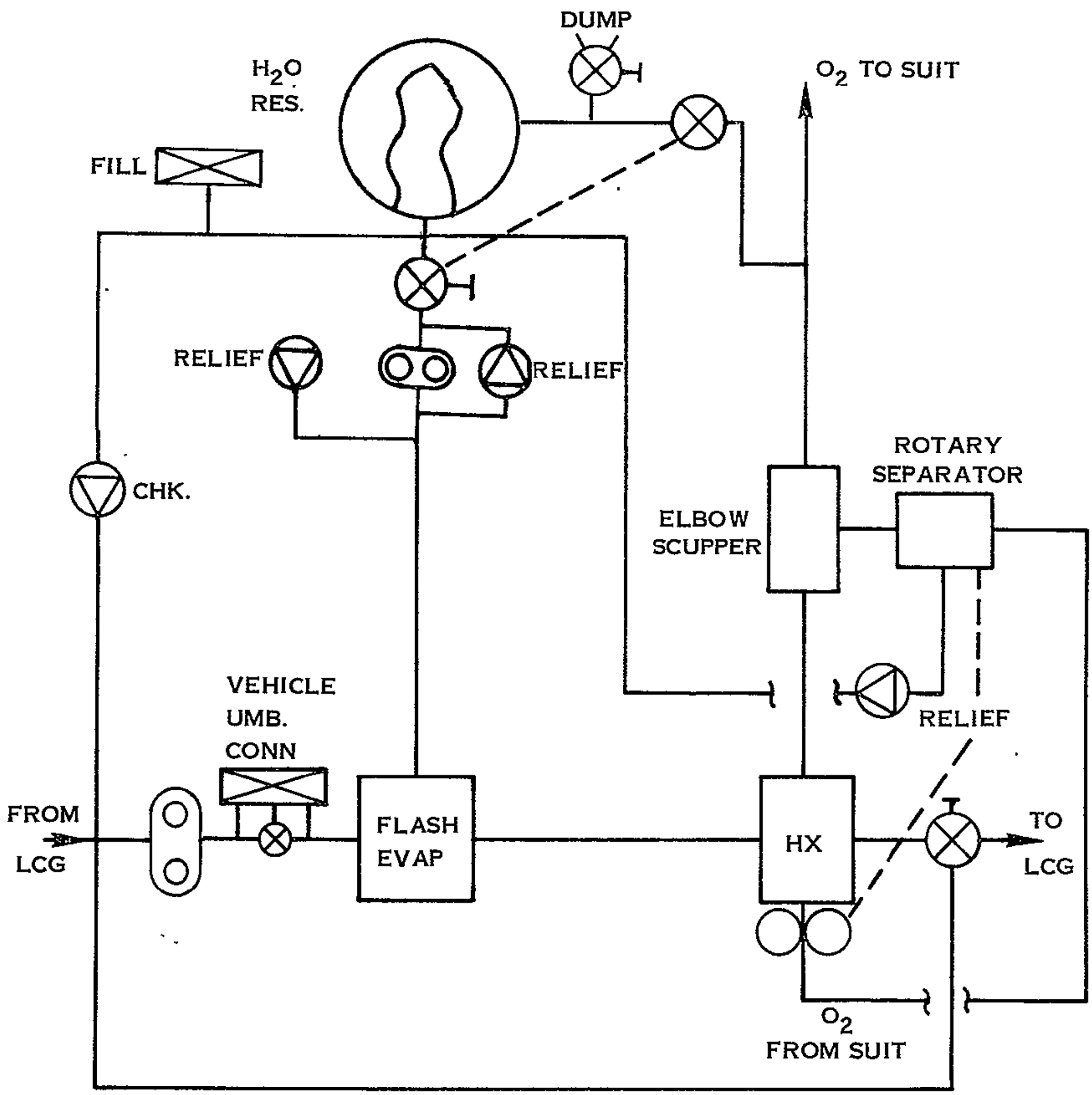
This concept consists of a simple bladder tank plus pump WMS, a two-two fluid flash evaporator HRS, a first stage elbow scupper/second stage rotary separator condensate control system and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

This concept is similar to Concept #29, except the fan separator is replaced by a ventilation loop fan driven rotary separator for condensate transfer to the WMS. Recharge is accomplished utilizing the procedure outlined for Concept #26.

The component weight and volume breakdown and the vehicle weight penalty are as follows:

Component	System Weight Kg (lbs)	System Volume (in^3) m^3
Water Reservoir	1.0 (2.2)	(405) .0066
H_2O	3.31 (7.3)	--
Dump Valve	.14 (.3)	(6) .000098
3 Relief Valves	.14 (.3)	(3) .00005
Shutoff Valve	.09 (.2)	(6) .000098
Flash Evaporator Pump	.91 (2.0)	(15) .000245
Controller	.68 (1.5)	(40) .00065
Pump	.59 (1.3)	(15) .000245
Flash Evaporator	1.09 (2.4)	(196) .0032
Vehicle Connector	.23 (.5)	(6) .000098
Check Valve	.045 (.1)	(1) .000016
HX	.36 (.8)	(10) .000163
Elbow Scupper	.14 (.3)	(8) .00013
Venturi	.045 (.1)	(4) .000065
TCV	.14 (.3)	(6) .000098
Motor/Rotary Separator	.09 (.2)	(5) .000083
Fill Fitting	.045 (.1)	(3) .00005
Package	1.63 (3.6)	(82) .00134
Power Penalty		(82) .00134
Pump	.36 (.8)	
Flash Evaporator Pump	.73 (1.6)	
Flash Evaporator Controller	.18 (.4)	
Delta P	.41 (.9)	
Motor/Rotary Separator	.18 (.4)	
Total	12.3 (27.2)	(893) .015

Vehicle Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (44.2 Pounds) 20.1 Kg



CONCEPT 30. FLASH EVAPORATOR, SIMPLE BLADDER TANK, 1ST STAGE ELBOW SCUPPER, 2ND STAGE ROTARY SEPARATOR

CONCEPT #31

This concept consists of a simple bladder tank plus pump WMS, a two-two fluid flash evaporator HRS, a first stage elbow scupper/second stage elbow separator condensate control system and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

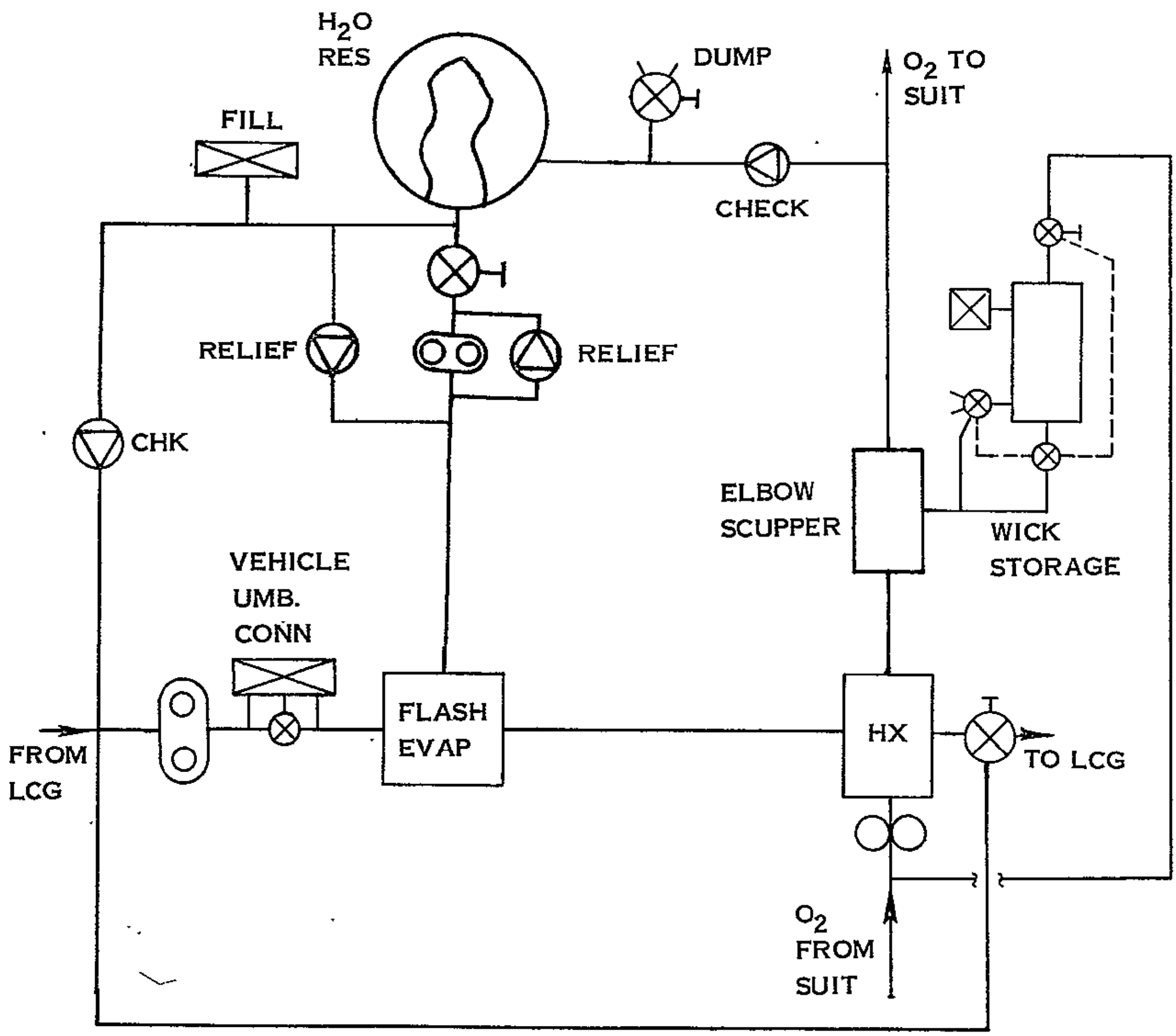
Operationally, this concept is similar to Concept #27, except humidity control is accomplished in two stages. The elbow scupper removes all the condensate from the main gas stream with a small amount of gas.

Recharge is accomplished utilizing the procedures outlined in Concept #27.

A component weight and volume breakdown and the vehicle weight penalty of this concept are as follows:

Component	System Weight Kg	(lbs)	System Volume (in^3)	m^3
Water Reservoir	1.09	(2.4)	(457)	.00745
H_2O	3.77	(8.3)	--	
Dump Valve	.14	(.3)	(6)	.000098
3 Relief Valve	.09	(.2)	(3)	.00005
Shutoff Valve	.09	(.2)	(6)	.000098
Flash Evaporator Pump	.91	(2.0)	(15)	.000245
Controller	.68	(1.5)	(40)	.00065
Pump	.59	(1.3)	(15)	.000245
Flash Evaporator	1.09	(2.4)	(196)	.0032
Vehicle Connector	.23	(.5)	(6)	.000098
Check Valve	.045	(.1)	(1)	.000016
HX	.36	(.8)	(10)	.000163
Elbow Scupper	.14	(.3)	(8)	.00013
Wick Separator	1.14	(2.5)	(160)	.0026
3-In-1 Valve	.18	(.4)	(6)	.000098
TCV	.14	(.3)	(6)	.000098
Drain Connector	.045	(.1)	(3)	.00005
Fill Fitting	.045	(.1)	(3)	.00005
Package	1.86	(4.1)	(95)	.00155
Power Penalty			(74)	.0012
Pump	.36	(.8)		
Flash Evaporator Pump	.73	(1.6)		
Flash Evaporator Controller	.18	(.4)		
Delta P	.41	(.9)		
Total	14.3	(31.5)	(1,110)	.018

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (49.9 Pounds) 22.7 Kg



CONCEPT 31 - FLASH EVAPORATOR, SIMPLE BLADDER TANK, 1ST STAGE SCUPPER 2ND STAGE WICK STORAGE

CONCEPT #32

This concept consists of a simple bladder tank plus pump WMS, a two-two fluid flash evaporator HRS, a first stage slurper/second stage rotary separator condensate control system and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

During operation, water enters from the LCG and is circulated, by the pump, through the vehicle umbilical connector shutoff valve, the flash evaporator, the vent loop to LCG HX, the temperature control valve (TCV) and back to the LCG. The LCG water is cooled in the flash evaporator and, in turn, the LCG water cools the vent loop O_2 via the vent loop to the LCG HX. During umbilical operation, the umbilical connector shutoff valve is closed routing all water to a heat exchanger in the vehicle which replaces the flash evaporator heat sink. Thermal comfort control is achieved by the TCV which varies the water flow to the LCG. LCG pressurization and makeup water is supplied via ground charged accumulator which is referenced to suit pressure.

The vent loop flow coming from the suit is circulated by the fan through the LiOH canister and the vent loop to LCG heat exchanger/slurper.

Water separation is accomplished in two stages. Approximately three percent of the main stream flow passes from the slurper to the upstream side of the fan. The pressure differential between these two points continually drains the condensed water from the heat exchanger. The water/gas mixture passes to the ventilation loop fan driven rotary separator which separates the water from the gas stream, and the gas is returned to the suit. The separator delivers the water to the feed water circuit through a relief valve which prevents the introduction of gas to the feed water circuit.

The pump in the feed water circuit provides water to the flash evaporator nozzle at the required operating pressure.

For missions requiring EVA in the non-venting mode, the reservoir is not recharged to provide the volume for storage of the separated water.

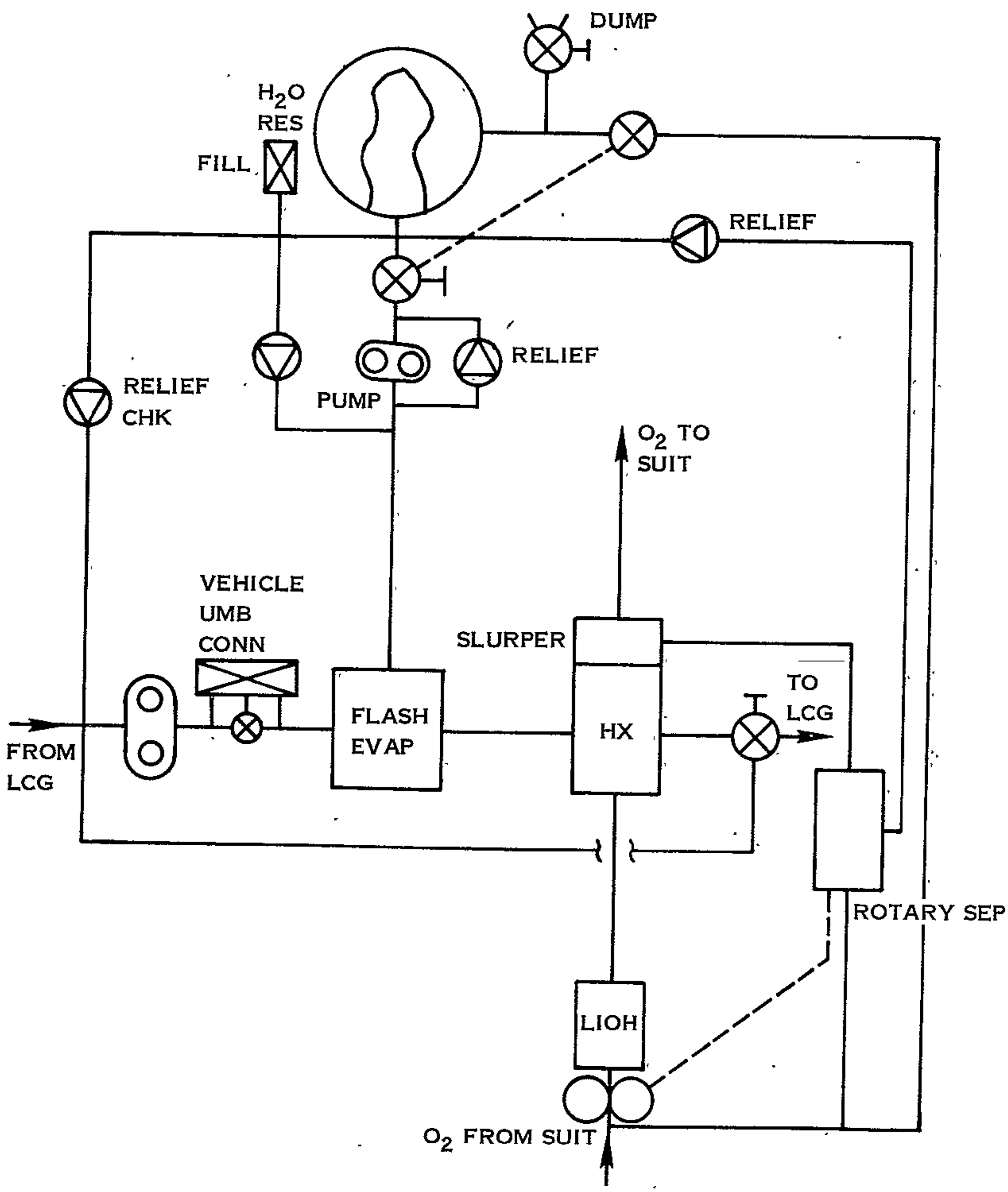
Recharge of the system involves the following steps:

Open the dump valve.
Connect the fill connector and hold.
Disconnect the fill connector.
Close the dump valve.

A component weight and volume breakdown and the vehicle weight penalty are as follows:

Component	System Weight Kg	(lbs)	System Volume (in^3)	m^3
Water Reservoir	1.0	(2.2)	(405)	.0066
H_2O	3.31	(7.3)		--
Dump Valve	.14	(.3)	(6)	.000098
3 Relief Valves	.14	(.3)	(3)	.00005
Shutoff Valve	.09	(.2)	(3)	.00005
Flash Evaporator Pump	.91	(2.0)	(15)	.000245
Controller	.68	(1.5)	(40)	.00065
Pump	.59	(1.3)	(15)	.000245
Flash Evaporator	1.09	(2.4)	(196)	.0032
Vehicle Connector	.23	(.5)	(6)	.000098
Check Valve	.045	(.1)	(1)	.000016
HX	.36	(.8)	(10)	.000163
Slurper	.14	(.3)	(10)	.000163
Rotary Separator	.09	(.2)	(5)	.000083
Fill Fitting	.045	(.1)	(3)	.00005
Package	1.63	(3.6)	(3)	.00005
Power Penalty			(81)	.00132
Pump	.36	(.8)		
Flash Evaporator Pump	.73	(1.6)		
Flash Evaporator Controller	.18	(.4)	(69)	.00112
Motor/Rotary Separator	.18	(.4)		
Delta P	.09	(.2)		
Total	12.0	(26.5)	(877)	.014

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (41.4 Pounds) 18.8 Kg



CONCEPT 32 - FLASH EVAPORATOR, SIMPLE BLADDER TANK, 1ST STAGE SLURPER 2ND STAGE MOTOR/ROTARY SEPARATOR

CONCEPT #33

This concept consists of a simple bladder tank plus pump WMS, a two-two fluid flash evaporator, a first stage slurper/second stage elbow wick separator condensate control system and a vehicle umbilical connector to permit up to 4.5 hours of umbilical operation with the HRS shutdown.

This concept is similar to Concept #32, except that the rotary separator is replaced by an elbow wick separator which is sized to contain the water separated during a four and one half hour EVA. Since the separated water is stored rather than utilized as feed water, the H_2O reservoir is larger than the tank in Concept #32.

Recharge of the system involves the following steps:

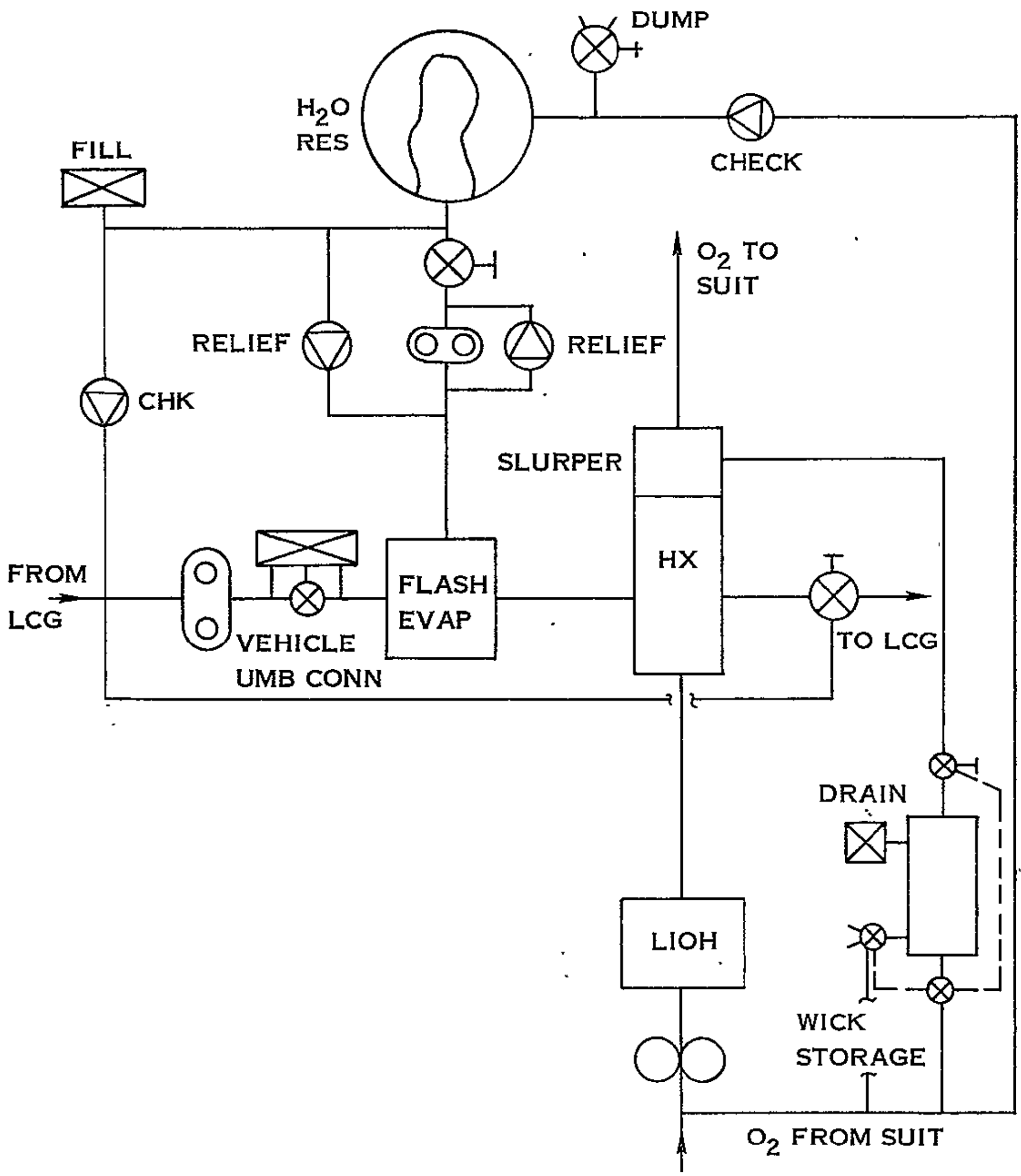
Close the three tier valve.
Connect drain fitting.
Open the EVLSS O_2 supply valve and hold.
Disconnect drain fitting.
Open the three tier valve.
Close the EVLSS O_2 supply valve.
Open the dump valve.
Connect fill fittings and hold.
Disconnect fill fitting.
Close dump valve.

The backside of the bladder in the separator must be vented to vacuum during EVA; hence, failure of the bladder or the three tier valve could expose the vent loop to vacuum. An orifice is incorporated in the three tier valve exhaust to control leakage in the event of bladder or valve failure.

A component weight and volume breakdown and the vehicle weight penalty are as follows:

Component	System Weight Kg	(lbs)	System Volume (in^3)	m^3
TCV	.14	(.3)	(6)	.000098
Water Reservoir	1.09	(2.4)	(457)	.00745
H_2O	3.77	(8.3)	--	
Dump Valve	.14	(.3)	(6)	.000033
3 Relief Valves	.09	(.2)	(3)	.000033
Shutoff Valve	.09	(.2)	(3)	.000098
Flash Evaporator Pump	.91	(2.0)	(15)	.000245
Controller	.68	(1.5)	(40)	.00065
Pump	.59	(1.3)	(15)	.000245
Flash Evaporator	1.09	(2.4)	(196)	.0032
Vehicle Connector	.23	(.5)	(6)	.000098
Check Valve	.045	(.1)	(1)	.000016
HX	.36	(.8)	(10)	.000163
Slurper	.14	(.3)	(10)	.000163
Elbow Wick Separator	1.14	(2.5)	(160)	.0026
3-In-1 Valve	.18	(.4)	(6)	.000098
Drain Fitting	.045	(.1)	(3)	.00005
Fill Fitting	.045	(.1)	(3)	.00005
Package	1.86	(4.1)	(94)	.00153
Power Penalty			(61)	.0099
Pump	.36	(.8)		
Flash Evaporator Pump	.73	(1.6)		
Flash Evaporator Controller	.18	(.4)		
Delta P	.09	(.2)		
Total	14.0	(30.8)	(1,095)	.018

Vehicle Weight Penalty = 2 (System Weight - Water) + Vehicle Power Penalty = (48.2 Pounds) 21.9 Kg



CONCEPT 33. FLASH EVAPORATOR, SIMPLE BLADDER TANK, 1ST STAGE SLURPER 2ND STAGE WICK STORAGE

APPENDIX K

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